
F.R.HARPER

OUR WONDER WORLD
A LIBRARY OF KNOWLEDGE

In Eleven Volumes

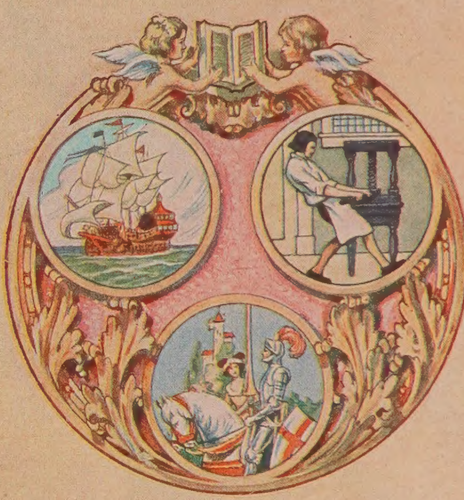
VOL. XI

Photos by Wm. L. Finley and H. T. Bohlman

THE WONDER OF FLIGHT

OUR WONDER WORLD

A Library of Knowledge



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VOLUME ELEVEN

THE WONDER OF LIFE

By MARION FLORENCE LANSING

For I will remember thy wonders of old. I will meditate also upon all thy work, and muse on thy doings. . . . Thou art the God that doest wonders.—Psalm lxxvii

But the glory of trees is more than their gifts:
'Tis a beautiful wonder of life that lifts,
From a wrinkled seed in an earth-bound clod,
A column, an arch in the temple of God,
A pillar of power, a dome of delight,
A shrine of song, and a joy of sight!

Van Dyke

AUTHOR'S INTRODUCTION

SINCE living is everybody's business, life must be everybody's interest. The more we know about it, the better we shall be able to understand it. The aim of this book is to make life more interesting.

Our title, THE WONDER OF LIFE, shows the spirit of the volume. Life is approached reverently and in a spirit of wonder. There are hundreds of separate "wonders" in the world, — queer creatures, strange happenings, and curious devices. Taken singly, each may be treated as a marvel, an oddity like the freaks of the circus. But this is neither the fair way nor the best way to view them. It is interesting to observe that the giraffe has a long neck, but more interesting to know how he came to have such a long neck, and most interesting to see how life portions out a long neck to the giraffe and a short neck to the turtle, according to what is most desirable for giraffe or turtle existence. In other words, the wonder of life as it meets all sorts of conditions and fits into all kinds of circumstances is more remarkable even than the hundreds of separate wonders which it creates. Given life in a plant or animal, and almost anything may happen — this is the outstanding thought of the book.

Such a volume would hardly have been possible a few years ago. Much of the knowledge presented in these simple stories is of very recent discovery. Then, too, the sciences — botany, zoölogy, physiology, and the rest — had each its little fenced-off section of knowledge, and a popular book which stepped over the fences without giving formal notice each time it went from one field to another ran the risk of being considered a trespasser. The fences have been coming down very rapidly of late. Research in one field reaches over into another. Our most distinguished philosophers and scientists put forth learned books and write scholarly articles in which they treat of human knowledge as a whole and draw examples from every quarter of the plant and animal kingdoms to support their conclusions.

The present volume takes advantage of this new freedom. Author and reader can wander over the broad territory at will, following life hither and thither. In these wanderings it is the author's part to act as interpreter and guide. The language of the scientist is often difficult of understanding by the untrained reader, though the story told may be of thrilling interest. It is the part of the interpreter to translate it into the familiar words of everyday speech. The regions are often unfamiliar. In some places the sights may be too strange for the newcomer to appreciate their full charm and meaning; in others, too common for the unobservant to take any notice.

The interpreter bears in mind two wise sayings, — first, "that it is the most familiar things in life that stand most in need of explanation"; and, second, that "small minds are interested only in the extraordinary, while great minds glory in the commonplace." The ordinary is so often found to be extraordinary, and the extraordinary to be an obvious working out of some familiar law, that it is never safe to take chances or look scornfully on any of life's handiwork.

The scheme and style of the book have been carefully adapted to the needs and interests of the average reader. He learns things he wants to know of the life about him and within him, and many things of which he has never dreamed concerning strange birds and beasts and fishes that dwell in the uttermost parts of the earth and the sea. This information is related by practical comments to his own experience. He is reminded that the humbler creatures have to go through the same routine as do human beings — of eating and sleeping, building homes, rearing a family and feeding it, keeping warm and dry and safe from their enemies — and he watches their lives to see how marvelously each one does it. He sees the gain of community life for them as well as for himself. He comes to value and appreciate his own body by comparing it with the bodies of birds and animals. He marvels that a tiny hole in the heart of the crocodile keeps him the dull and sluggish creature that he is, when if it were stopped up, as it is in higher creatures, he might rise to a higher plane of life. It is one of the specialties of the book that the necessary but difficult facts and truths of physiology and hygiene become simple and fascinating when matched with the life of all the world. If birds and beasts can take as much trouble as they do to obey the laws of healthful living, boys and girls can do their easy part to keep themselves fit.

Contents and chapter headings tell the story of the volume so fully that it need not be further told here. For the reader who is interested in the accepted divisions of human knowledge, it may be said that he is getting an introductory course in almost every branch of the sciences which deal with life. Even the most modern of studies, the science of food and nutrition, is quite fully covered as it relates to proper diet. Since life is "a current sent through matter," it has been thought well to include a very simple and untechnical story of the new knowledge concerning the constitution of matter. It is the hope and expectation of those who have planned the volume that the would-be student will get from it something that he would not get from the studies taken separately and in more detail, for he is having them all fitted together into a harmony of life. The case is not unlike that of the man who said he "could not see the wood because of the trees." If we stand surrounded by a birch, a maple, an oak, a cedar, a pine, an ash, an elm, a hemlock, we note them as separate kinds of trees and miss the total effect of line, mass, and color. So in studying Nature in itemized and classified sciences, such as geology, botany, morphology, chemistry, physics, biology, zoölogy, etc., we may fail to catch the vision of the glory and majesty and mystery of the natural world.

The information has been gathered from a wide range of sources and sifted and resifted, to be not only instructive and accurate but also entertaining and practical. Both manuscript and proof have been read and criticized helpfully by Dr. Hervey W. Shimer, Professor of Paleontology at the Massachusetts Institute of Technology, author of "An Introduction to the Study of Fossils," etc., whose constant encouragement and coöperation have been invaluable. It has taken three years to gather from leading specialists of America and England — from Dr. Shufeldt, S. Leonard Bastin, Edward Bigelow, Dr. Longley, Rollo H. Beck, Mr. Watson, Mr. Brownell, and many others — the photographs which have made the volume so rich to the eye as well as to the mind. These photographs show at first glance that they are the work of master photographers and Nature students. Almost as soon as the work was undertaken, Mr. William L. Finley was persuaded to coöperate in its creation by allowing the use — in many cases the exclusive use — of a hundred or more of his most special photographs, treasures drawn from the collections of many years. He has since been appointed to obtain moving pictures of wild life all over the country for the National Geographic Society of Washington. We are doubly fortunate to be able at the time when he is engaged in this valuable public service to be presenting these beautiful studies. The volume shares with the rest of the set the distinction of having drawings made especially for it by skilled artists to present graphically in picture as well as in text many striking points. The work is secondary in the sense that it is a grouping of facts discovered and recorded by others rather than an original study of plant or animal life. In such a work the facts must, of necessity, be drawn from a wide variety of scientific literature. They have been verified wherever possible, and sources are on record, though not cited in wearisome detail in the volume. In such new fields as one or two chapters cover, a month or a year may bring a slight shifting of the evidence from one side to the other; but the great truths are unchanging. The power of the book is in its spirit; the facts are illustrative, a means of inspiring interest rather than an end in themselves.

Marion Florence Lansing

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VOLUME XI

FULL — PAGE ILLUSTRATIONS

In addition there are 230 illustrations in the text, of which those with titles are catalogued under their respective subjects in the Index.

"THE WORLD BELOW THE BRINE"

"The world below the brine,
Forests at the bottom of the sea — the branches and leaves,
Sea-lettuce, vast lichens, strange flowers and seeds — the thick tangle, openings, and pink turf,
Different colors, pale gray and green, purple, white, and gold — the play of light through the water,
Dumb swimmers there among the rocks — . . .
. . . breathing that thick-breathing air as so many do. . . ." — WHITMAN.

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THE WONDER OF LIFE

LIFE is the real wonder of the world. It is the Wonder-Worker that takes lifeless matter and by a magic touch changes it into a blossoming plant, a darting fish, a soaring bird. It runs through matter, "cutting out in it living beings all along its track," shaping all through which it passes as a potter shapes clay. Itself unseen, it creates a Wonder World that is marvelous in our eyes.

In this book we shall follow the trail of life as it winds over the world. We shall begin our journey at our own doorsteps, and we shall return in the last chapters to find life working miracles in our own bodies as marvelous as any which we have seen the wide world over. But between the first page and the last we shall see many strange sights and learn many curious and interesting facts. We shall follow life four miles up into the air, and we shall drop with it five miles down into the ocean depths. We shall see a slender, delicate little plant bore a hole in an Alpine snowdrift by the power of its own heat and push bravely up to the light of day. We shall gaze upon the giant trees of the Pacific Coast which have seen four thousand winters and four thousand summers. We shall watch while a bird so small that it could be held in one hand travels ten thousand miles over an uncharted highway of the sky, beating its silent way through the air by the power of the little engine which life has set at work within its body. We shall watch life swim and creep and walk and run and climb and fly. We shall visit many countries and pick up many interesting acquaintances. We shall hunt out the armadillo in South America to see the armor which he carries on his back, and the frilled lizard in Australia to see him spread out his wide neck-frill in surprise and indignation. We shall meet the penguin, most remarkable of birds, that walks upright like a man when he is on land and flies like a bird when he is under water. We shall see fish that carry torches in the dark ocean depths, and fish that walk, and crabs that climb trees and take journeys.

We shall learn how Nature clothes its children and feeds them and keeps them warm and dry and safe. We shall peep into Nature's nurseries. We shall watch birds and beasts and fishes as they go about the business of daily life, as they catch their food and eat it, as they build homes for themselves and their children, as they use the tools and weapons with which they are equipped. We shall match our own lives at every turn with the lives of the humbler creatures of the world, and if, as we go, we give ourselves gladly to fellowship with all other living things, we shall gain by each step a new sense of the value, the beauty, and the glory of the life that is ours.

It will be a leisurely journey, in which we stop at any moment to look at anything that is alive.

Because it is alive it is sure to be interesting. The frog in the garden and the spider spinning a web on the grass are as wonderful as the less familiar creatures that live across the seas. The lives and adventures of the birds of the homeland are as interesting as those of the strange birds of the tropics. The youngsters on the opposite page have had no need to go far from home to satisfy their sense of wonder. Children have a feeling of kinship with and interest in the living

Photo by Wm. L. Finley

A HUNGRY NESTFUL

Four red-winged blackbird nestlings.

things about them. Older people can easily regain it. It is good for us to turn from the cares and the routine of our daily lives to see how the mother bird feeds her hungry nestful and trains her children in the ways of the world. Because we are not hurried we can inquire intimately into the lives of birds and beasts and insects. We can try to see with their eyes and hear with their ears and smell with their noses. We can study the machinery of their lives, and so come naturally to the machinery of our own. Seeing what powers animals have and what they accomplish with them, we shall be ready to appreciate the wonders of our own bodies and the priceless gift of our own mental powers.

"The longer I live," wrote John Burroughs, "the more my mind dwells upon the beauty and the wonder of the world." Of all the living beings "cut out" by life, we are the only ones who look on at the world and wonder at it. Plants and animals spend their energy within the cycle of their own little lives. Man has a wonderful surplus. He alone stands, as it were, outside himself and looks on with awe and admiration at himself and his fellow men and at the whole world and all its marvels far and near. The world of the lower creatures must be very matter-of-fact and prosaic. A cow sees grass as something to eat; you and I see grass as beauty, as color, as the sign of springtime and summer, as a soft, living blanket for the earth. Even we may see it differently. To the child it is good to play in, comfortable and pleasant; to the farmer it is food for his cattle; to the botanist it is a kind of plant with a given name, for to him there are grasses and grasses. Each one of us sees the world differently because of what we have in ourselves. That is why we like to find out more about all these living things. They will mean more to us if we bring more interest and knowledge to our look at them. Man with his wonderful powers brings more, far more than any other living creature. He is kin with the Creator. When all the beasts of the field and the fowl of the air had been formed they were brought "unto the man to see what he would call them: and whatsoever the man called every living creature, that was the name thereof." The poet sees in the sky the man-of-war bird, who has "slept all night upon the storm," and is "now a blue point, far, far in heaven floating." He thinks of all that the bird has seen in his wonderful around-the-world flight, and ends his poem thus:

"Thou born to match the gale, (thou art all wings,)
To cope with heaven and earth and sea and hurricane,
Thou ship of air that never furl'st thy sails,
Days, even weeks untired and onward, through spaces, realms gyrating,

At dusk that look'st on Senegal, at morn America,
That sport'st amid the lightning flash and thunder-cloud,
In them, in thy experiences, hadst thou my soul,
What joys! what joys were thine!"

Man alone looks below the surface of the outer world. He seeks to know life's laws and to penetrate its mysteries. Gradually the secrets of life are being laid open to him; the wonders of the world are being unrolled before his eager gaze. So, as we go, we need not be content to see only the outside show, wonderful as it would be simply as a pageant that passed before us. We may ask questions and receive answers from those wise men who have traveled this way before.

Much depends on the spirit in which we go. "The sense of wonder," writes a British naturalist, "is a precious gift, one of the saving graces of life. It makes for happy and hopeful expectancy, it keeps the mind young and growing. There should be *something* before which we say, with the wise man of old, 'This is too wonderful for me.' If we let the sense of wonder die out, the world will lose its light and our ways their lightsomeness." In this spirit let us follow together the trail of life, not forgetting to give thanks to the good God who is the Creator of life and who has so made us that we can wonder and marvel and delight in His works. "O Lord, thou art our father; we are the clay, and thou our potter; and we all are the work of thy hand."

BECAUSE IT IS ALIVE IT IS INTERESTING

"All knowledge," says Coleridge, "begins and ends with wonder." Children begin with "the first wonder, which is the child of ignorance." As they learn of the world about them they come to "the second wonder, which is the parent of adoration."

TWENTY-FIVE FEET LONG

THE SEA SERPENT OF FISHERMEN'S TALES

The oarfish, with a body from twenty-five to thirty feet long and almost as thin as a ribbon, is very probably the creature which gave rise to many remarkable yarns, told from ancient days until now, of "sea serpents" met by fishermen in their voyagings. The silvery body, crossed with dusky stripes, the grotesque head and face with enlarged fins tipped with red waving above like a horse's mane, might well give foundation for almost any story. Oarfish have been taken on the Pacific Coast. The body has so little texture that it melts away on the shore in the sun.

Photo by S. Leonard Bastin

THE ALPINE SOLDANELLA GROWING IN SNOW

LIFE IN ACTION

As seen in a flower that bores a hole in a snowbank, in fishes that live under tons of water, in a squash that lifted four thousand pounds, in a silkworm that multiplies its weight daily by five hundred, in hair that grows four hundred and fifty cells an hour, in microbes found alive after four thousand years.

"LET us, then, be up and doing" is the motto, the one great law of all living things. Life is always active. That is why it is so fascinating to study. It is always doing something, doing it well, and doing it toward some end. As an active force, it has four leading characteristics: it goes everywhere, it never stands still, it has the power of growth, and it builds. Each of these characteristics we shall illustrate briefly in this chapter.

LIFE GOES EVERYWHERE

There is something thrilling about the way life catches hold wherever it can find a spot upon which to rest. Climb the high peaks of the mountain ranges of Switzerland, and away up in the snow, blossoming bravely in the little warm hollow which it has made for itself, will be found the delicate nodding pink or blue bells of the Alpine Soldanella. This flower has such a powerful little furnace within itself that it not only keeps itself warm but melts the snow beneath which it is buried and bores a way up through the crust to greet the warm sunlight. Sometimes it is buried so deep that it cannot reach to the surface but hollows out a little cave in which to bloom. Its temperature when blooming has been recorded as 102 degrees Fahrenheit, and it has been found in a cave or chamber a foot wide and three feet high which it has hollowed out of the hard-packed snow for itself. Yet it is as delicate and soft to the touch as a bluebell.

In the regions of the north and south poles there is teeming life in every sheltered spot. Members of the Shackleton antarctic expedition cut down through fifteen feet of ice and found at the bottom a rich vegetation and a swarming animal life. In later stories we shall

Photo by Wm. L. Finley and H. T. Bohlman

GOLDEN EAGLE

The eagle and the condor rise to great heights in the ocean of air which surrounds the earth.

see how the arctic plains blossom luxuriantly for a six weeks' summer.

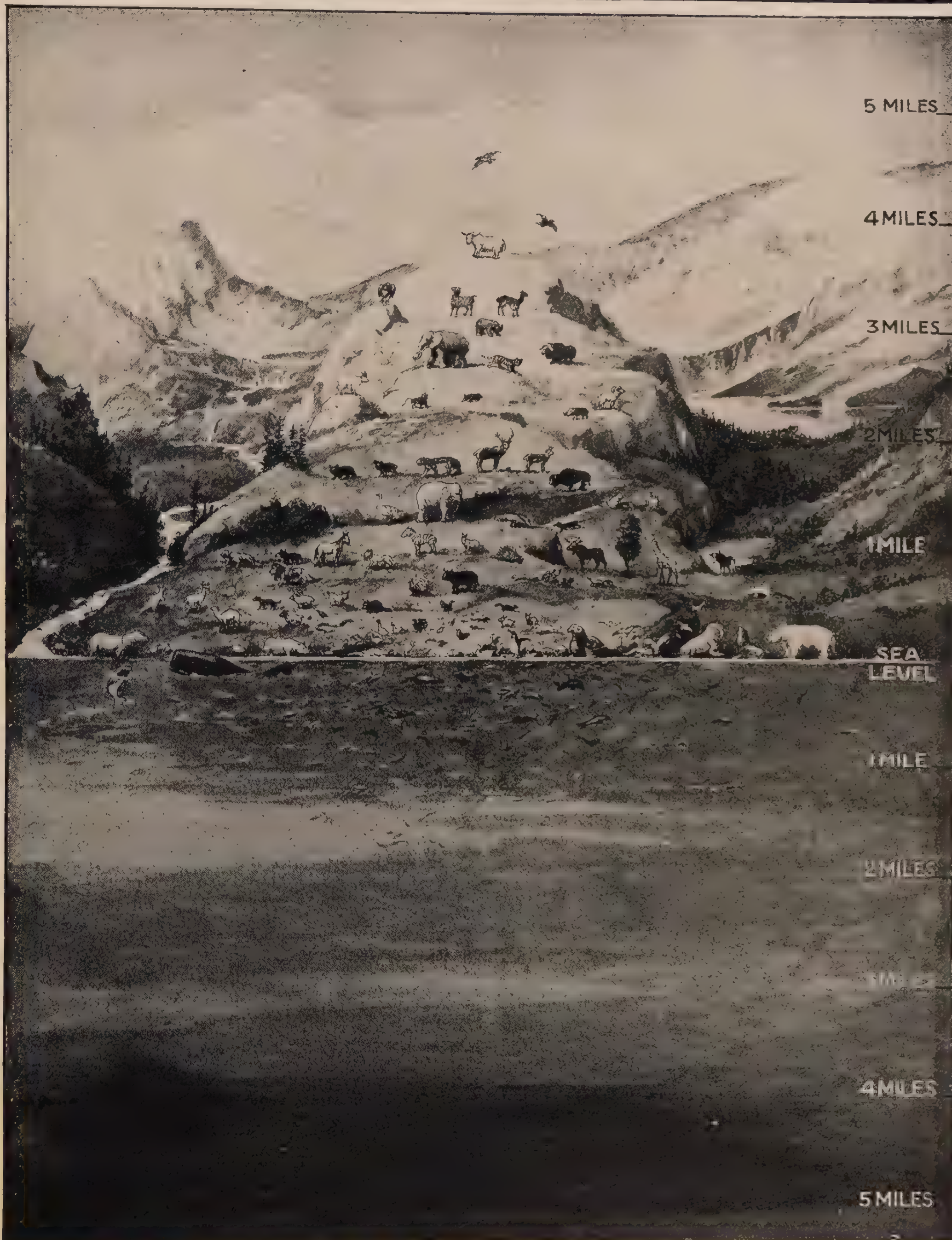
The ocean is peopled with an abundant life. In the color plate facing page 1, life at widely varying depths in the ocean is compressed into a single sketch to give us a conception of the varied plant and animal life with which the great waters teem. "The World Below the Brine," Whitman has called this wonder world which lies beyond our sight and experience. His poem fits our picture as if two halves of a whole had come together.

"The world below the brine,
Forests at the bottom of the sea — the branches and leaves,
Sea-lettuce, vast lichens, strange flowers and seeds — the thick tangle, openings, and pink turf,
Different colors, pale gray and green, purple, white, and gold — the play of light through the water,
Dumb swimmers there among the rocks — coral, gluten, grass, rushes, and the aliment of the swimmers,
Sluggish existences grazing there suspended, or slowly crawling close to the bottom,
The sperm whale at the surface blowing air and spray, or disporting with his flukes,
The leaden-eyed shark, the walrus, the turtle, the hairy sea leopard, and the sting ray,
Passions there, wars, pursuits, tribes, sight in those ocean depths, breathing that thick-breathing air as so many do. . . ."

Five miles down in the ocean, in cold dark depths where tons upon tons of water are bearing down on them with an enormous pressure, there dwell fishes which carry on a successful existence and even manufacture in their own bodies lights which illumine the dark world in which they pass their lives.

Four miles above sea level on the mountain slopes of Tibet the giant yak climbs from crag to crag. In the ocean of air which surrounds the earth, only a few birds rise so high as this heavily coated ox of Asia. His brothers and cousins, the domesticated yaks, have come partway down the hill slopes to be beasts of burden; but the yak of mountain breed does not range lower than fourteen thousand feet above sea level and is met as high as twenty thousand feet and more. The condor and the eagle, in their parts of the world, match him on the heights, and near him in the column of life come the vulture, the llama, the vicuna (of the llama family) and the spectacled bear. Life is most familiar to us and most abundant at or near sea level. But when we make a vertical column of life, it measures from eight to nine miles. The animals as they group themselves from sea level up one, two, three, and four miles into the air, form a living pyramid against the green or

A NINE-MILE COLUMN OF LIFE



FOUR MILES UP AND FIVE MILES DOWN

Such is the range of animal life if measured vertically. Life is most abundant at sea level, but the giant yak goes four miles up in the air on the mountain slopes of Tibet, and there are strange fishes which live in the ocean depths. (See Notes for key to the animals in this picture.)

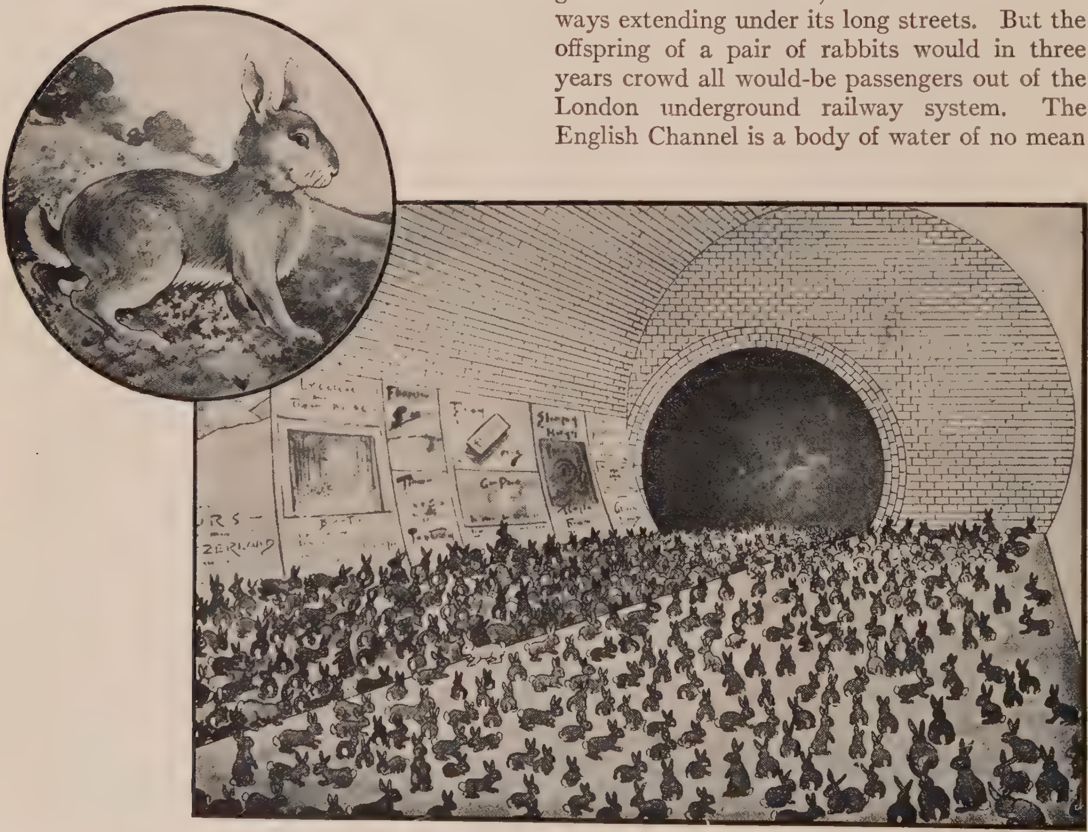
snowy background of the lower hills or higher peaks. They are most abundant at sea level and in the first mile; from the first-mile mark to the second there is a brave but diminishing array, with the bear, the puma, the elk, the pronghorn, and the bison in the upper levels; from the second-mile mark to the third there is a lesser mountain company; and beyond the three-mile mark only the few which can breathe in the high altitudes and find a living on the barren slopes. Such is the range of life as our artist has graphically set it forth for us.

LIFE NEVER STANDS STILL

Life may well be found everywhere, for it never stands still. It is always moving, expanding, increasing, multiplying. One cell divides and becomes two; these two divide and become four; the four divide and become eight, and so it goes on. In twenty minutes there are five hundred; and before long the numbers have gone far beyond our count. The lobster lays ten thousand eggs at a time, and the queen bee five million during a lifetime of four or five years.

"IF THEY ALL GREW UP"

The British naturalist-photographer, Leonard Bastin, supplies the interesting and amusing pictorial studies of "what would happen if all the progeny of animals lived and grew up." "All the calculations," he writes, "are based on estimates by famous men of science." Study them for yourselves. London is one of the great cities of the world, with a network of subways extending under its long streets. But the offspring of a pair of rabbits would in three years crowd all would-be passengers out of the London underground railway system. The English Channel is a body of water of no mean



Copyright, S. Leonard Bastin

IF THEY ALL GREW UP

What would happen if all the baby creatures grew up? The offspring of a single pair of rabbits would in three years crowd all would-be passengers out of the underground railways of London.

dimensions; but if all the eggs of a single female cod grew up and then each "cod-child" bred once, and they all stayed in the English Channel, the water would be pushed out. There would soon be no water channel at all, but a solid bridge of cod. Life multiplies with prodigal lavishness; its surplus, particularly its surplus of young life, is the food supply of the world.

THE POWER OF GROWTH

We are all familiar with the way living things grow. The power to grow is the unique characteristic of a living organism. As in the case of many familiar occurrences, we are likely to underestimate the force which Nature is so quietly exerting to bring about the rapid growth which we observe in plants and young animals. Each year, for instance, squashes grow from seed to fruit in our gardens, quietly, with no buzzing of machinery or letting off of steam. Yet when a young squash was harnessed in a laboratory, it was found to exert an almost incredible force by the sheer push of its growth. Here is the story of this experiment as it was tried in an agricultural college.

A SQUASH THAT GREW WITH A FORCE OF TWO AND ONE-HALF TONS

A young squash vine was selected and placed under conditions most favorable for growth. A flower was fertilized and when the young squash was well started it was placed under a steel harness and in a wooden cradle in such fashion that its expansive power was free to play against a lever, while the squash itself was protected from being crushed under the weights which it was expected to raise by means of its growing power. The lever arm, the fulcrum, and the weights were adjusted,

IF THEY ALL GREW UP

If all the eggs produced by a female cod grew up and bred once, the English Channel would be solid with fish. A large codfish was found when dissected to contain about eight million eggs.

and the observers awaited results. This is the table showing, by the record of weights lifted, the incredible mechanical energy developed by the growth of that squash.

August	21	60 lbs.
"	22	69 "
"	23	91 "
"	24	162 "
"	25	225 "
"	26	277 "
"	27	356 "
"	31	500 "

By the eleventh day of September it was carrying over one thousand pounds; its load was thereafter increased for a time at the rate of one hundred pounds a day. The October record is as follows:

October	3	2115 lbs.
"	12	2500 "
"	18	3120 "
"	24	4120 "

"On October 31, when the harness gave out under the strain, a weight of five thousand pounds was raised sufficiently to make it clear that with proper support even this would have been carried by the squash." Parts of the weighing machinery had had to be renewed, and an oak beam and finally iron supports to be used in place of the first light apparatus. The weight of the squash when taken out (dug out and cut out by a chisel) of its harness was forty-seven pounds. Within it were seeds "apparently perfect and in normal numbers"; that is, while the squash was carrying this heavy weight it was also performing its proper business of creating new life for another generation. "When we contrast the normal texture of a squash with that of tree trunks and roots, and cast our eyes upon the table showing the growing force of the former despite their apparent disadvantage, it is not to be wondered at that growing trees displace the best-laid pavements and are able to disrupt rocks and buildings if once they can gain the entering wedge." The tree in the picture has split in two the boulder which man would have had to use dynamite to crack.

THE WONDER OF A GROWING GARDEN

A squash grows from seed to fruit in a garden, quietly, with no buzzing of machinery Yet a growing squash when harnessed in a laboratory lifted thousands of pounds by the force of its growing power.

GROWTH BY MULTIPLYING CELLS

When we study "How Life Begins," as we are going to in a later chapter, we shall know more about a cell's power of increase by multiplying and multiplying and multiplying again. Dr. Keen, Professor Emeritus of Surgery in Jefferson Medical College, gave in a recent article most interesting examples of the amazing facts of growth as exhibited by living things. A plant, an animal, a human being, — all are alike in that they grow from a single cell. But how fast some of them grow! Human children have a long protected life history before they come to an age when they must fend for themselves, but lower in the scale of life the period of infancy is shortened. A silkworm baby must go about the business of growing more speedily. In thirty days after it is hatched, says Dr. Keen, it increases in weight fifteen thousand times; that is, five hundred times its original weight each day. On the same rule a baby if it weighed seven pounds at birth would weigh thirty-five hundred pounds the very next day, and when a month old would weigh one hundred and five thousand pounds or more than fifty short tons. Such a comparison is startling in the extreme. "This is a gross, unimaginative way of looking at such a phenomenon. When we analyze it seriously, what a wonder world we enter upon! How these little silkworms must feed, feed, feed! Think of the abounding life in each microscopic cell. Every one has to multiply itself five hundred times in twenty-four hours." Every cell must be working feverishly at top speed. Yet all happens in so quiet and orderly a manner that no one looking on suspects the enormous forces at work.

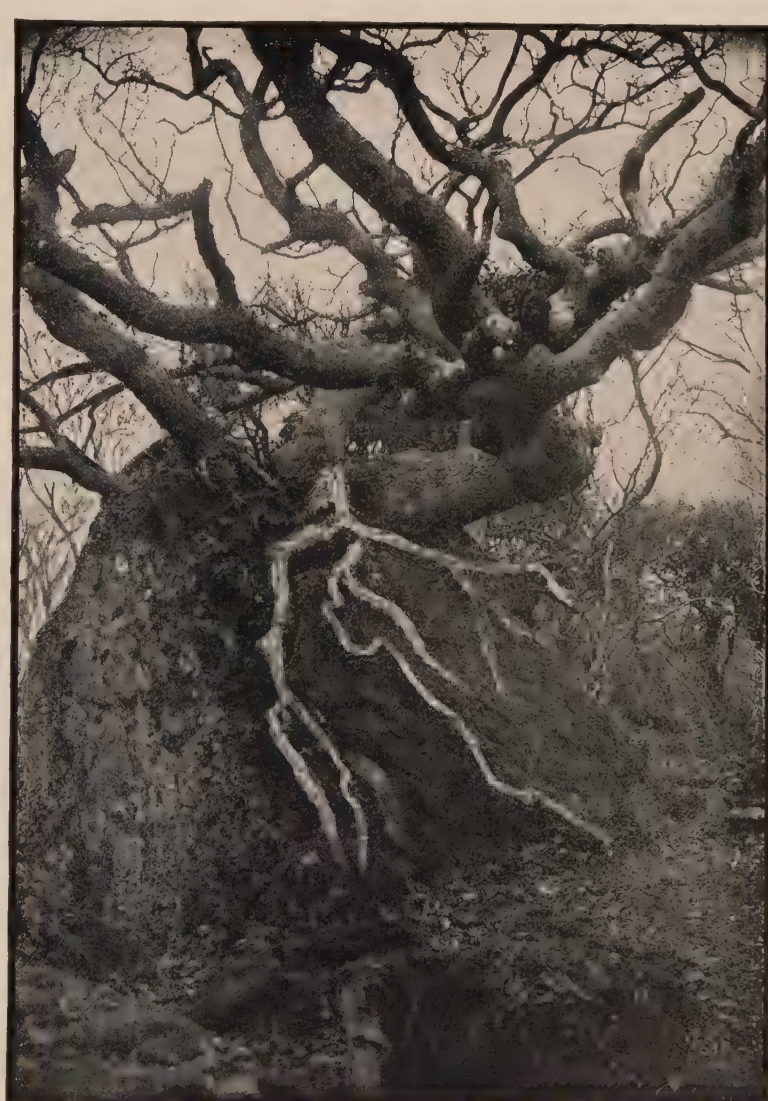


Photo by S. Leonard Bastin

A GROWING TREE AS IT SPLIT A BOULDER

An acorn started to grow in soil on top of the rock. Its roots needed soil and took advantage of small cracks and fissures in the rock. Before the tree was grown the rock was split in all directions.

HOW FAST DOES HAIR GROW?

By collecting fragments of hair shaved from the face, Dr. Keen measured the rate at which hair grows. Each hair had grown about one millimeter (one twenty-fifth of an inch) in twenty-four hours. The number of cells in that length of one single hair was calculated from examination under the microscope to be ten thousand, eight hundred and thirty-five. This would indicate a growth of more than four hundred and fifty cells every hour, day in and day out. Figures piled upon figures become so large as to cease to have meaning. But let us follow the matter one step further. If there were five thousand hairs on the face, and each hair grew this amount each hour, there would be over two million cells an hour, or over fifty million cells each day. "Cut the figures in half if you wish," comments Dr. Keen. "The fact is just as marvelous."

Photo by Philip O. Gravelle

HAIRS OF A MAN'S HEAD
(Magnified 100 Diameters)

A living piece of hair is made up of hundreds of tiny units called "cells." In one twenty-fifth of an inch of hair there are nearly eleven thousand cells.

LIFE PERSISTS

Equally marvelous with the power of life to catch hold wherever it can gain a chance, is its power to keep its hold under difficult conditions. Because life goes out of living things before our eyes, while we look on, we sometimes think life is frail and delicate, a will-o'-the-wisp flitting hither and thither. That is only one side of the picture. Life does not easily give up its hold on the matter with which it has associated itself. The seed which has been lying in a box all winter does not look promising, but the gardener knows that within that dry brown covering lies imprisoned a magic something which will respond when it has been given the right conditions. His cultivation of the soil and his sowing of the seed and watering and tending it would be of no avail if it were not for the miracle of life within. Sometimes we have amazing exhibitions of the persistence of this life. Here is the story of a seed that held its life for five thousand years, as it was beautifully told in a current periodical.

A LITTLE EGYPTIAN GIRL AND HER SEEDS

"This spring, in Pennsylvania, were planted seeds that had been taken from the hand of an Egyptian mummy, and they grew. Five thousand years ago, in that land of the Nile, lived a little girl who loved flowers. When the child died and they prepared the body for the long, long sleep, they put into her hand the seeds of her favorite flower. Having a haunting hope that the human soul survives death, they also had a shadowy thought that seeds and other things had a spiritual life which could travel on into the world beyond the shadows, with the patient spirit that journeyed outward from the familiar earth. They hoped that the dear child might be able to have her favorite flowers in the spirit world."

MORNING-GLORIES FIVE THOUSAND YEARS OLD

"So the years crept on; and century was added to century. Kingdoms grew and became great and their power waned. Mighty armies marched to conquest and to dust. Generations came and went. In the quiet of the ancient tomb were the tiny seeds in the hands of the little mummy. After five thousand years they came to light again. From the Old World to the New they were brought. And, strange to relate, they grew in the soil of the New World. From

those seeds came beautiful little blue morning-glories.

"What had preserved their life so long? Not the protecting hand of the mummy of the dead child, but the power of the living God. It is the same power that preserves life in the earth from age to age. Let us hope that the immortal spirit of the little Egyptian maid can know that her flowers live again, and that she rejoices again in their beauty. They live again under the same sun that shone on Egypt. The waters of the Nile have flowed to the sea, moved with the tides, evaporated again and been blown as clouds over the earth. They have come down as rain and snow in distant lands. They have moved with the vast and majestic currents of

Photo from life, by R. W. Shufeldt

SEVENTEEN-YEAR CICADAS—NATURAL SIZE

These insects are emerging into a sunlit world after seventeen years underground. In the crotch of the tree is the chrysalis or "shell" from which the insect above has come. In that time Nature could build five generations of camels, four or five generations of lions or tigers, and three of brown bears. After all this preparation the cicada lives only a few weeks.

air and sea through the ages. The earth, the waters, the sun, the air,— these are abiding but changing elements. Greater than these is the power that can preserve life in the earth, that makes this world a habitable home for the human family. When a man has watched his field ripen, he rejoices that the grain is ready for the reaper. When all is harvested he looks with great content upon his well-filled granary. But only God can preserve the life in the seed for next year's sowing."

BURIED ALIVE SEVENTEEN YEARS

Seventeen-year cicadas, in our own country, have an amazing life history. Their immature young, their larvae, are buried alive for seventeen years. Any one coming upon them in their underground resting place during this long period would pass them by as "worms." When for each larva the appointed time is up, it bursts its tiny chrysalis covering and comes out. After so long a wait, its life as a full-grown locust lasts but a few weeks. In some years a great many of these long-buried insects come to the end of their seventeen-year cycles, and we have a visitation of cicadas; in other years only a few come to the end of their appointed slumbers.

Animals which spend the winter in sleep seem to come as near the edge of life as would be safe. They almost let themselves drop over into the sleep of death. But somehow they hold on, and come out from the winter sleep ready to take up their activities again. Insects which hibernate can be frozen solid and remain frozen for weeks and months and still retain the power of coming to life again.

ALIVE FOUR THOUSAND YEARS AGO — ALIVE NOW

A winter sleep or a seventeen-year sleep is as nothing to the long vacation taken by certain tiny organisms recently discovered by a French scientist in ancient Egyptian papyrus (paper). Our other Egyptian story was of a seed; this is of actual living organisms. In the course of his researches he found living creatures in paper of the present day — paper that had been sterilized in water heated to the boiling point, the temperature at which life usually ceases. When he took the paper to pieces, shredded it, removed some of these tiny organisms and gave them a chance, they began to move, showing that they were alive. He tried the same experiment on eighteenth-century paper, and then on fifteenth-century paper; in both cases, they "came alive." He got hold of a book printed in the year 1492, the year of the discovery of America, and here, too, were microbes embedded in the paper which, when given suitable conditions, moved about freely and behaved in all ways like the same kinds of microbes of twentieth-century birth. A Chinese manuscript written long before the discovery of printing gave similar results. Imprisoned in it were little creatures which had held the spark of life through all the centuries.

"These very remarkable results fired M. Galippe's interest to such an extent that he determined to carry the question of the long life of these little particles still farther," continues the report. "From a well-known Egyptologist he succeeded in obtaining fragments of papyrus belonging to the time of the Ptolemies, that is, about 2000 years before the Christian era. . . ." These, too, were treated for results. "After three hours of hydration [combination with water] these intra-cellular micro-organisms, *which had remained motionless for so many centuries, all began to move.* After the lapse of twenty-four hours cultures made with them exhibited signs that they were *multiplying and developing.*" Such were "the startling and unexpected results of the revival of life in organisms as dead apparently as Pharaoh's mummy." For four thousand years these creatures, so small that they were between the cells of papyrus, had held something of that mysterious force of life, so that under favoring conditions they could pick up their existence at the point where they had apparently laid it aside for ever. The hundred-year sleep of the Sleeping Beauty of our childhood fairy tales is brief compared to the four-thousand-year slumber of these microbes, which M. Galippe has called "tiny Methuselahs."

LIFE THE MASTER BUILDER

Life might have all the characteristics we have mentioned — it might appear every-

LIFE'S REQUIREMENTS

The gift of life is like the gift of the ten talents in the Bible parable. It carries with it requirements. The man who wrapped his talent in a napkin and buried it in the ground had that talent taken away from him. No outside force presses us on to meet the requirements of life; but life carries with it its own impulse for continuance. We all want to keep alive. Even while we feel life thrilling to our finger tips, we are moved by a deeply planted impulse to be about the necessary doings which will keep that life flowing as freely and as abundantly.

THE NEED OF FOOD

One universal requirement that life puts on all of us is the need for food. Every living thing needs food. Food is the fuel by means of which life keeps up its fires, the stuff out of which life builds its growing, self-wasting, self-renewing creations. One of the most interesting story studies in this book tells how in spite of what would seem to us impossible obstacles all sorts of creatures manage to get their food. If we were beings of a different order, kept alive without effort on our part for food, we should not be so interested in the way animals keep up their food supply. Our interest comes from the fact that we have to do the same thing. Food getting is a business that the possession of life forces upon us.

THE IMPULSE TO RENEW ITSELF

Closely akin to this impulse or instinct to keep life going in ourselves, with its food requirement, comes the more mysterious impulse to pass life on to another generation. Life does not create, run out, create, and run out again in spasmodic episodes. It is self-renewing. To this impulse we owe the scattering of seeds at harvest time, the building of nests and the laying of eggs in the spring, and all the manifold activities which have to do with the provision for and care of young new living things.

SELF-PROTECTION

With these two main impulses which all share, go minor impulses which grow out of them or are in some way involved with them. If life is to be continued in a plant or an animal, that plant or animal must protect itself. This is done in a thousand ways, from the thorny prickles of the cactus and the bristling quills of the porcupine, to the soft protective coloring of birds and beasts and fishes and the powers of movement and flight.

In the instincts for self-protection and self-preservation we are one with the plant-animal world. The least protected in surface bodily structure, human beings are by their nervous systems and their brain power the most able to protect themselves.

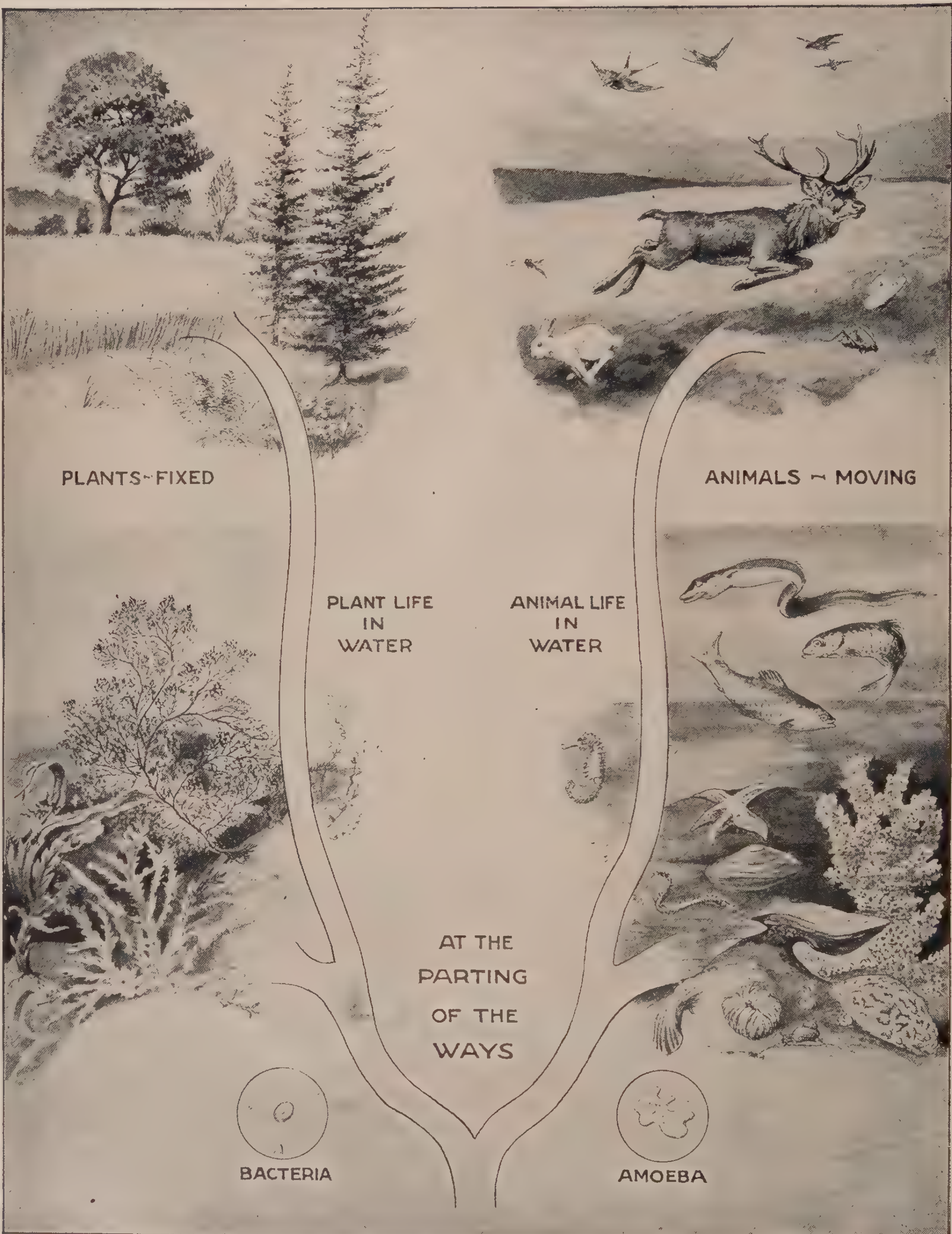
IF A MAN'S ARMS WERE TIED

Recognizing and enjoying this kinship in life and its requirements with all our living neighbors on the planet, let us enter into their problems and see how cleverly and in what a myriad ways they have solved them. Mr. Beebe has suggested the plight that a man would be in if he were placed in the position of a bird. Tie a man's hands and arms tightly behind his back, stand him on his feet, and tell him he must find and prepare his food, build his house, and defend himself. His situation, says Mr. Beebe, would be not unlike that of a bird. Hence, the wonderful and varied development of beaks and bills with which all these processes are successfully accomplished. Suppose we were rooted in one place, as plants are rooted, how could we obtain food and sustain and perpetuate life through many generations? It is such questions as these that are answered by our study of life in this volume.

FROM ONE WONDER TO MANY WONDERS

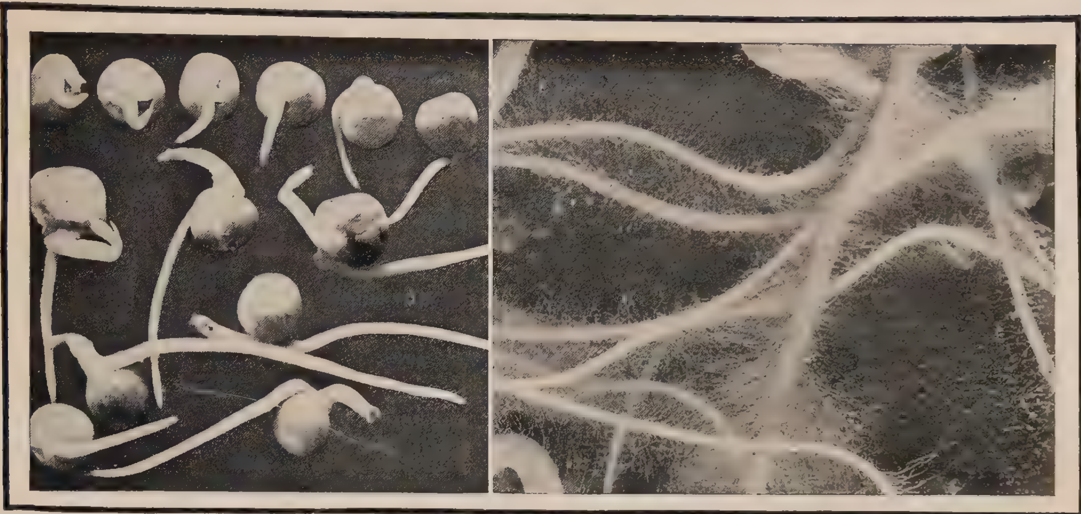
Starting with unity, with life, our common possession, we come out into a world of marvelous variety and complexity. The most intricate mechanism of our most complicated machines, with their thousands of parts, is simple compared with the structures which life builds, uses, and discards every season. Starting with the "Wonder of Life" we find ourselves enjoying the contemplation of an amazing and most entertaining collection of separate "wonders," each interesting in itself and the more interesting as a single expression of the greater "Wonder of Life."

HOW PLANTS AND ANIMALS PARTED COMPANY



PLANTS TO STAY STILL — ANIMALS TO MOVE

It is as if plants said, "We will save the energy that comes to us from the sun; we will stay still and store it"; and animals said, "We will take the risk; we will spend energy as we go, using it in free movement."



SEEDS AND ROOTS

Photos by E. F. Bigelow

TO MOVE OR NOT TO MOVE

The variety of life—how plants stay still and animals move; the economy of life—how plants store energy and animals get it by eating plants; the rewards of life—how animals took a chance and won.

ONCE upon a time — and there is no better way of beginning a story which is half true and half what we imagine to be true but cannot prove — once upon a time a big choice was made which had its effect upon the life of every human being. It was not a conscious choice, such as you or I would make if we stood at a crossroads and had to decide which way we should take. But there was a crossroads, and half the living creation went one way and half went the other. How that choice was made no one could say. That it was made, that all the world did not travel in one direction but that half went along the plant road and the other half branched off and took the animal road, we can all see for ourselves. Because that choice was made, you and I can walk and run instead of being rooted to one spot for the whole of our lifetimes. Because of it, too, we have to eat three meals a day to keep alive, — which is another part of the story. There were no signboards at this crossroads; each group of cells that made one of the first plants or one of the first animals was simply following a tendency. But if we, looking back from the vantage of the wonderfully developed world of to-day, were to place at that spot signposts describing where each road would lead, we should mark the road which the animal half of creation took "To Move" and the other road which the plants followed "Not to Move."

PLANT OR ANIMAL

First-plants and first-animals were undoubtedly much alike. It is easy to believe science when it tells us this, for it shows us at the same time tiny plants and animals of to-day which are so much alike that it takes a learned scientist to tell them apart. Indeed, some of these same tiny living things are claimed in both kingdoms and are listed in both botanies and zoölogies. No one looking at photographs of some of these smallest plants and animals on page 21 would care to risk much on a guess as to which were which.

All plants and animals are more alike than a mere glance at their "outsides" would lead us to think. They are all made of the same life-stuff; they are all built on the same pattern of cells upon cells upon cells, grouped in colonies, each cell filled with that life-stuff; and they all share in the common possession, life. They differ in the way in which this life principle works within them; and the most conspicuous difference is in their ability or tendency to move about or stay still.

ALL DEPEND ON THE SUN

This difference came about as a matter of convenience in the getting of a living. We have seen that all living things have to keep themselves alive. This they do by means of energy, which they derive from the sun. Sun energy keeps the world going. The life impetus is not sufficient for prolonged existence; after it has been given, the living being, be it plant or animal, must have some energy supplied from without. Therefore it seeks food which will supply this energy. But where does the food get it? The store of energy for all the world is the sun. The sun pours in energy in the form of sunlight and sun heat indiscriminately upon every living thing. The difference between plants and animals is in the way they get and use this energy.

HOW PLANTS CHOSE TO STAY STILL

As we observe the kingdom of plant life, it is as if in that Long Ago, when the first plant-animals stood at the parting of the ways, with energy pouring in on them for their use as money might be supplied to us, some of these tiny living cells, singly or in groups, said to themselves:

"Here is this energy, which is ours for the taking. Let us keep it, storing it for our own use and to start our children off well in the world. Then in the days when the sun does not send us so much light and heat, we shall be safe; we shall still be able to keep up life."

So these cells became plants. They kept and developed to its highest perfection the power of getting energy and keeping it. They became able to reach out as if with invisible fingers into the air about them and take and hold the elements they needed for a living, working them over by means of the sun's energy and so storing energy food for themselves and for their children. They packed energy food in stems and roots. They stored it about the tiny life germ of their seeds. They developed bulbs and fruits and a dozen devices for storing energy.

Since air containing the food elements they needed was all about them, and since through the air the sun energy came to them, they did not have to waste any of their hard-won energy in moving about to find food. Sufficient to them a sunlit, airy spot. As soil supplied certain elements needed in their food, they must reach down into it with their roots and keep always a close connection with it. So their life habit came to be one of staying still, rooted in one spot for all the days of their lives, busy about their work of storing energy.

HOW ANIMALS TOOK A RISK

Other cells or groups of cells met the question differently. It is as if they said:

"We will store and keep on tap what energy we must have to live for short times, but the rest of this wealth which pours in on us, we will spend as we go. We will use it in free movement. What we may lose in safety we ought to more than make up in the freedom that will come through our use of this energy."

Results justified the risk the animals took, and they have survived and flourished to this day. More and more they have developed along the line of energy spending. But they could never have got to the high point which they have reached if it had not been for their less venturesome neighbors, the plants. If animals ever did have the plants' power of taking their food elements from the air, they have long since lost it. The quicker and easier way for them to get food was from the plants, which in their zeal for energy getting and energy storing were producing an oversupply far beyond that needed to perpetuate their kind by seeds. So animals have now come to the point where they use their power of motion to go out and find for themselves food from the plant or lower animal worlds.

That plants can afford to feed the animal world is shown by their continued prosperity. That animals gain greatly by this choice which they once made is shown by their varied and wonderful development and attainments. How the choice affected their structure and habits, how some plants still kept a degree of power to move and some animals let themselves be rooted to the ground, will be told in later stories.

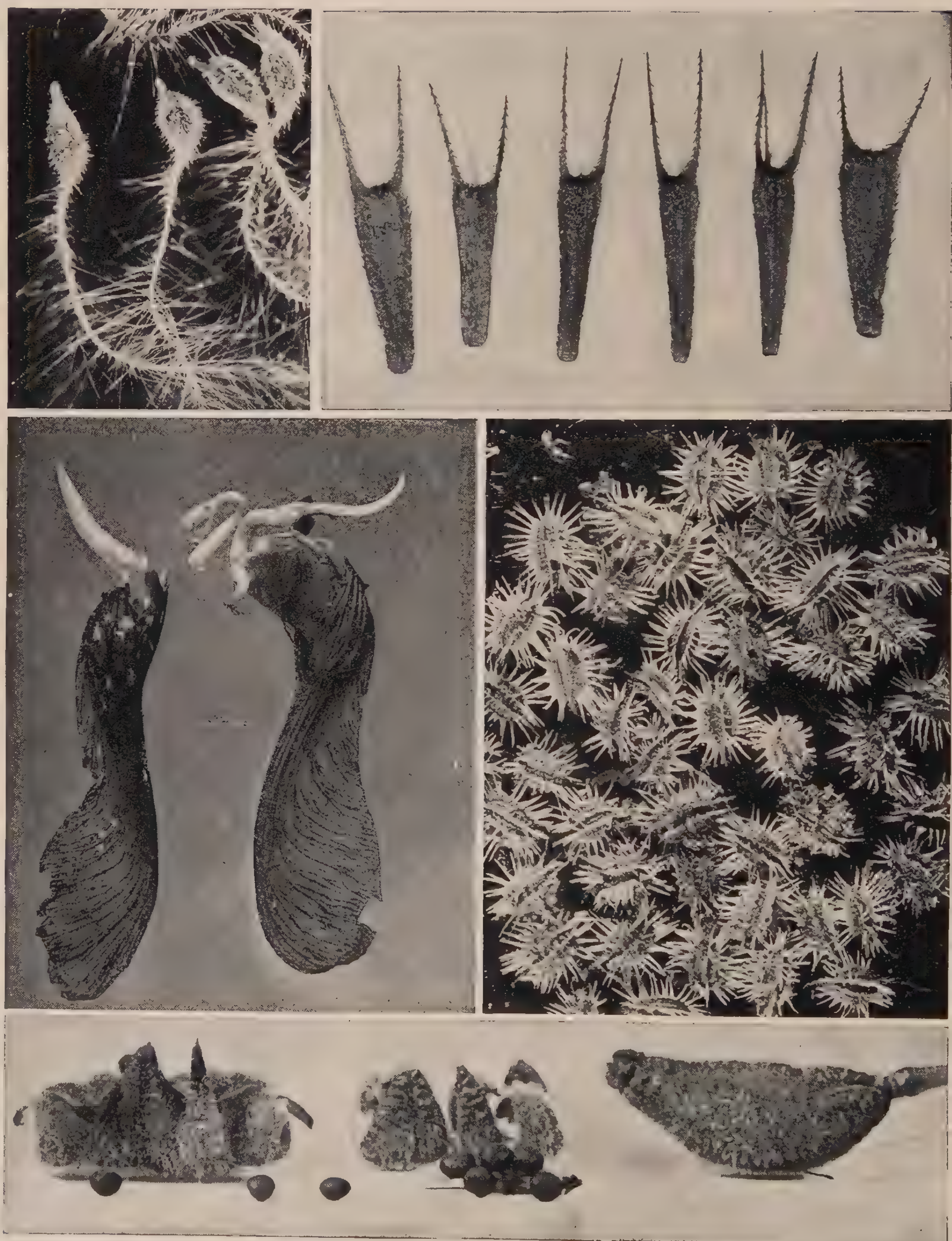
THE SMALLEST PLANTS AND ANIMALS THAT LIVE

Photo by E. F. Bigelow

AS THE MICROSCOPE SHOWS A WORLD OF LIFE BEYOND OUR VISION

Each white dot in the upper picture is a complete flowering plant. Two pinheads (marked with crosses) give the scale for size. The whole colony or cluster of plantlike animals below is not so large as a pinhead.

SEEDS ARE THE WORLD'S GREATEST TRAVELERS



Photos by E. F. Bigelow

SEEDS EQUIPPED FOR THEIR JOURNEYS

At the top is the clematis with its long, plumy wings, ready for seed flight, as are the two airplanes of the maple directly below. To the right of the maple wings are "stick-tights," ready to catch a ride, their barbs magnified in the picture directly above. At the foot of the page balsam is shooting its bullets.

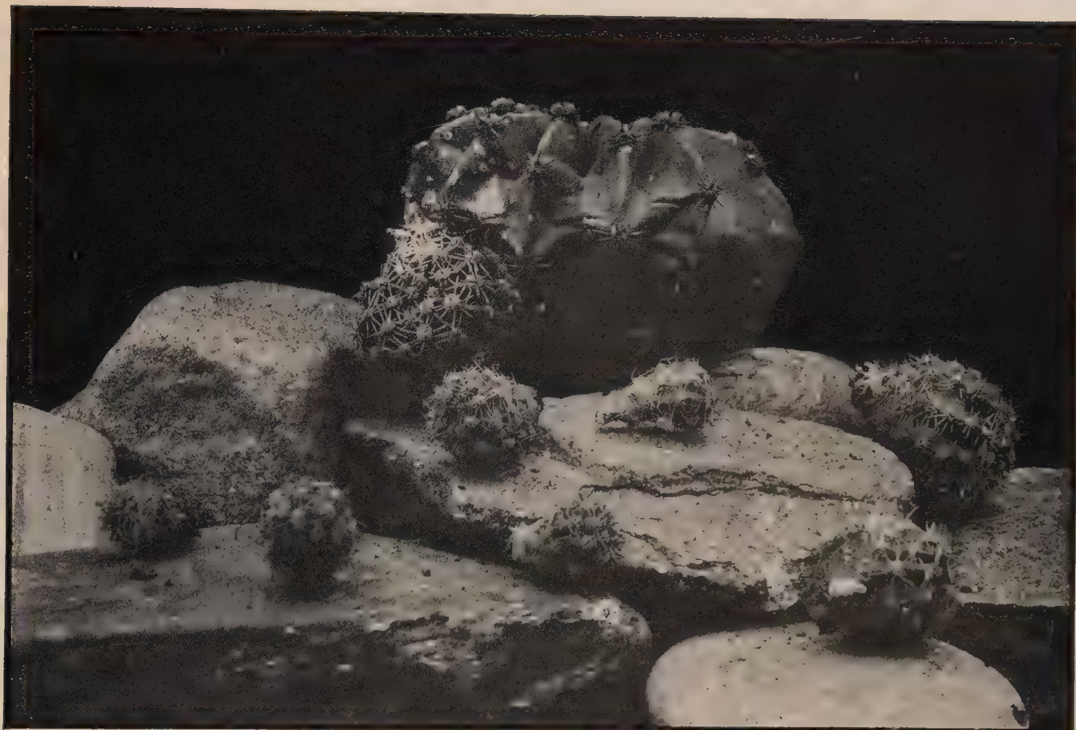


Photo by S. Leonard Bastin

CACTUS BUDDING OFF LITTLE PLANTS WHICH ROLL AWAY

HOW PLANTS TRAVEL

The cleverness of life, as seen in its many devices, in plants that walk, that run, that shoot, that fly, that swim.

WHEN plants gave up for themselves the power of free and untrammeled movement, as it is possessed and cultivated by animals, they could not safely deprive their children of its advantages. If all the seeds from a plant dropped straight to the ground beneath that plant, there would be an overcrowding and an exhaustion of the soil which would soon result fatally for both seed and parent plant. Some plants solved the difficulty by keeping for themselves a very limited power of motion, which would enable them to re-root themselves at spots within a small area. Most of them wrapped the precious life germ in easily transportable seeds, counting on forces within themselves or outside agencies to carry on the necessary business of seed distribution.

Wind and water, plants and animals, are all pressed into the service as seed carriers, with the curious result that while plants cannot stir they are more successful in scattering their offspring up and down the earth than the animals which can roam hither and yon at will. Nowhere can the observer see for himself more easily and more clearly Nature's marvelous power of bending all agencies to its own ends than in the summer and autumn pageant of seed scattering.

SOME PLANTS KEEP THE POWER OF MOTION

These are the plants which have not traveled far from the plant-animal forking of the road. Simpler plants like simpler animals hitch themselves along by the movement in one direction of their cell contents. Algæ, members of the

Photo by S. Leonard Bastin

WALKING FERN

A bud forms at the tip of the frond of the fern. When the tip touches the earth the new plant roots in the soil. So the fern "walks" or "jumps" from place to place.

seaweed group, seem to swim, beating the water with tiny threads or hairs, or contracting and expanding in a way that propels them. Diatoms send out threads through the windows of their self-built palaces by means of which they move themselves and their houses along the sea or lake bottom. Such plant activities are chiefly of interest as signs of the original unity of the plant-animal world.

MOVEMENT BY GROWTH

We all recognize that when plants chose to stay still in a single spot of the earth's surface, they did not give up entirely so necessary an attribute as the power of movement. From their chosen spot they reserved the right to swing root, stem, and tendril within limited areas. The plant which finds itself in danger of being suffocated for lack of air, restricted beyond the point of safety in its food-making power through insufficiency of light, or dried for lack of water, can reach up or down, east, west, north, or south until it finds what it needs. Resisting the down-pulling force of gravity it can climb walls and trees.

PLANTS THAT WALK

Some plants can likewise use their limited power of movement to spread and propagate. They do not follow the usual plant custom of sprouting solely from seeds, but swing out new buds or plants which will root for themselves. The strawberry sends out its surface runners, so formed at the joints that they can root where they stop, starting a new life but in vital connection with the parent plant until they have strength to fend for themselves. Wandering Jew, trailing arbutus, and walking fern bear in

their names evidence of their power to travel. At the tip of the frond of the walking fern, as shown in our photograph, a bud forms and develops as a baby plant. This happens while the frond is still swinging in the air. Then when the tip of the fern is bent by wind, rain, and the burden of its own weight to touch the earth, the new plant reaches down into the soil, takes root, and grows until it, too, can start a bud at the tip of a leaf. So the plant may be seen "walking" from spot to spot in our shaded fern beds. Potentilla, of the cinquefoil family, is shown creeping hither and thither over a rock in search of spots with the few grains of soil which it must have for its new roots. Wintergreen, white clover, sweet potatoes, currant bushes, brambles, and many members of the grass family are familiar examples of this method of traveling and rooting again at a distance from the mother plant. A Bermudan plant, the *Bryophyllum calcinum* shown on page 27, has a very curious method of perpetuating itself. It produces at the notches, or scallops, in its large, thick leaves, buds which develop into baby plants. The leaf falls to the ground, and these plants root for themselves wherever they fall, till soon there is a little colony growing in the vicinity of the original plant.

Interesting as all these examples are, they serve to show the limitations of plant life in general; let the plant do its best, it cannot by its own power of movement by growth extend the field of possibility for its children more than a few inches or a few feet at best. Only by wrapping up the precious life germ in an easily transportable package and then sending it out into the world to fend for itself can plant distribution be effected. The resulting package, as we all know, is the seed. The methods of seed distribution are varied and interesting.

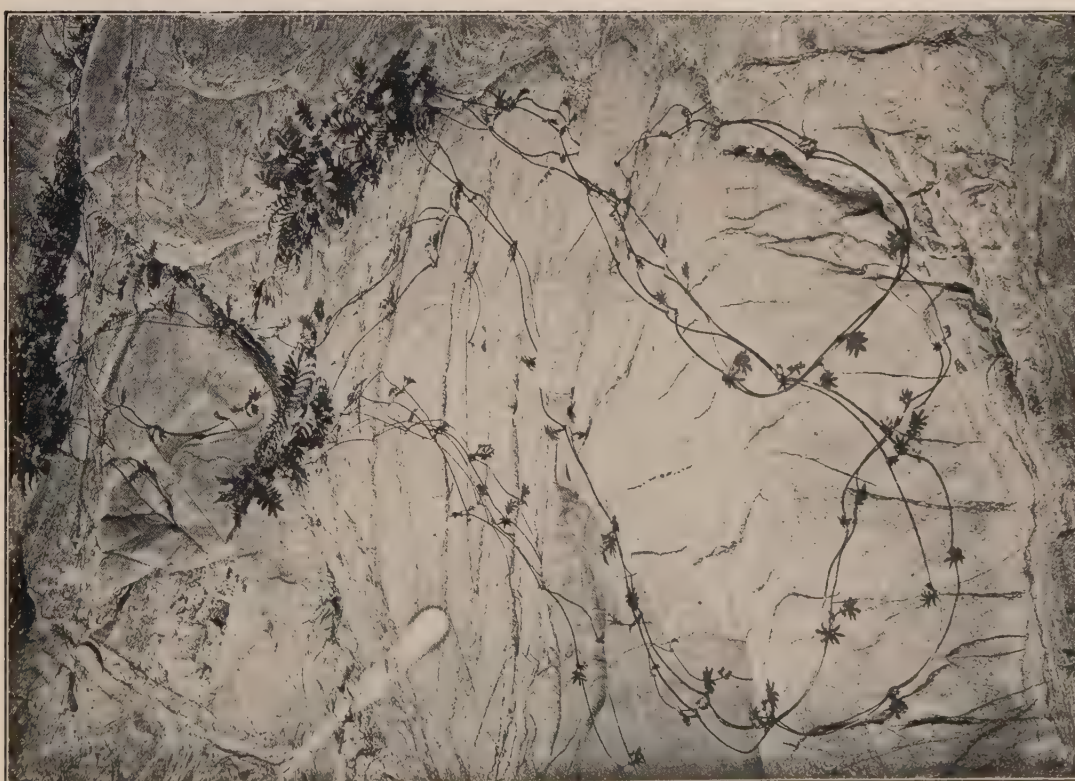


Photo by S. Leonard Bastin

POTENTILLA OR CINQUEFOIL (FIVE-FINGER)

This rock does not look an encouraging place for a plant, but the potentilla is sending out long stems to locate soil in the crevices where it may get a root-hold.

PLANTS THAT SHOOT

Some plants manage to give their seeds a good start without any outside help. A boy may be held fast in a single spot, but if his pockets are full of pebbles and his arms are free to throw them his range is extended far beyond the reach of his own arms. Plants do not have the conscious power of projection which the boy has, but they have developed clever automatic devices by which they can get the same result that the boy gets when he throws a pebble. They can shoot their seeds far beyond their own power to carry them or to follow them.

The squirting cucumber does this by as clever a hydraulic engine as one would ever wish to see. The pressure of liquid against the thin walls of the fruit causes it to burst at the right moment and send out a shower of seeds and liquid. Witch-hazel and balsam shoot their seeds out as if through a popgun by the springing force of dry elastic tissues. So pigweed fires its seeds. All these and many others work on the principle of the gun or the sling shot, a propelling piece of machinery suddenly set to work by the application of some force, and capable of hurling to a considerable distance the light, compact seed-bullets.

Here again, however, the range is limited, ten, twenty, or thirty foot measuring the outside limit of its circle of possibility. For effective distribution the plant must depend on outside agencies. These Nature supplies in wind, water, and animals. For carriage by these agencies the plants must fit their seeds. No package was ever more carefully wrapped to meet the requirements of express or parcel-post transportation than the life germ of the plant is wrapped in the

Photos by E. F. Bigelow

PIGWEED SHOOTS ITS SEEDS TO ASTONISHING DISTANCES

At the right are shown the black seed-balls and the caps; at the left the sockets after the balls have been fired. What power must be pent up in these pods to throw these big balls out from their walls!

PLANTS THAT SHOOT

SQUIRTING CUCUMBER

THE GUNS OF THE WITCH-HAZEL

The squirting cucumber is a European plant, the fruit of which swells with water and finally bursts, "squirting" its seeds many feet. The sides of the ripe witch-hazel pod press against the seeds, driving them out with tremendous force, sometimes to a distance of forty feet.

A PLANT THAT SHEDS BABY PLANTS FROM ITS LEAF

A DANDELION "GONE TO SEED"

Photo by E. F. Bigelow

EACH SEED POD HAS ITS BALLOON READY TO SAIL AWAY

The dandelion proves the success of its mode of travel by the way it scatters its seeds with their feathery tops far and wide.

PLANTS THAT BUILD AIRSHIPS AND HYDROPLANES

AIRSHIPS WITH ROOMS FOR SEED AVIATORS

BURDOCK HOOKS
That catch on clothing and fur

A BURDOCK HEAD (magnified)

BURDOCK SEEDS
Packed like toothpicks, as the hooks carry them

A PLANT THAT ANIMALS CARRY

MILKWEED GONE TO SEED, WITH ITS SAILS SET

shape, size, and weight of package which will make it best fitted to its own particular transportation agency.

SEEDS THAT FLY

Wind is an excellent carrier. Plants have developed to a high point of skill the art of building flying machines. The principle is that of the airship or airplane,— to expose much surface to the wind, as in sail or wing, with comparatively little weight. The maple and the clematis show two kinds of airships, the maple catching the wind by a wing, the clematis by long, plumy hairs. Dandelions work on the parachute plan. Their rapid spread over the earth's surface shows it has worked well. Ailanthus and bladder nut build bladders in which the seeds may lie, to float in the air or on the water as circumstances may make desirable. Fully two-thirds of the seeds of plants are said to depend on the wind as carrier. If the wind deposits them in a favorable spot, they live and flourish; if not, they die. So abundantly has the parent plant reproduced itself in seeds that scores upon scores may die and still the proper proportion of plant life be kept up.

WATER TRANSPORTATION

Water transportation is simple and successful. An air-filled bladder will keep the seed vessel afloat until it is ready to discharge its cargo, while a waterproof skin or husk will keep its contents dry. Coconuts float in their woody husks from island to island of the tropical seas. The story is told of the sea coconut, with a double butt, which was picked up in the Indian

Photo by S. Leonard Bastin

THE GRAPPLE PLANT AS CARRIED ON A SHEEP'S HOOF

This remarkable photograph shows how this South African plant — well named for its grappling powers — has attached its woody fruits with hooked thorns to the foot of a sheep. These fruits with their seeds will be dropped off along the route of the sheep's wanderings.

Ocean or on its shores for many years by sailors and natives and regarded as a botanical curiosity until the parent palm was finally located on one of the Seychelles Islands.

ANIMALS AS CARRIERS

With the animal kingdom absolutely dependent on the plant kingdom for its existence, it is fitting that animals should perform some service for plants. Plants took on themselves the labor of food making, and in so doing gave up the power of locomotion. Animals which kept and developed this power may well put it at the service of their plant neighbors.

Birds carry seeds in their feet. Darwin tells of getting eighty seeds to germinate from one clodlet of earth taken from the foot of a single bird. Multiply this even in part by the number of times during the season of seed sowing in which a bird rises from one spot and flies to another, and we get a faint conception of the possibilities of transportation by this free-moving branch of the animal kingdom.

Birds and animals eat many seeds which they cannot digest. It is one of Nature's favorite methods to clothe a well-protected indigestible seed with a tempting fruit covering, to make a bird or an animal select it as an appetizing bit and so transport it a considerable distance. Squirrels and other smaller creatures collect nuts or other seeds and bury them, then forget them or become unable to make their way back to them.

CATCHING A RIDE

The best way to cover distance for the seed is to catch a ride, and for this innumerable seeds are fitted by their shape. Feathers and fur of animals, even the clothing of men, are very good lodging places for seeds. Sticky seeds, with a coating of mucilage, cling best to feathers; hooked and barbed seeds work their way best into hairy skins and furry coats. Burdock sends out from each plant dozens upon dozens of seeds with hooks which enable them to steal a ride on the back of an unsuspecting animal. Sticktight's barbed hooks can hardly be avoided in the pastures where it grows. If poetic justice demands that animals render through their power of free movement a service to the plants which serve them, animals certainly fulfill their mission.

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SNAPPING TURTLE

ANIMALS IN ARMOR

The armadillo with a coat of mail, the turtle in a shell, the fish that lives in a box, insects with breastplates—what they gained and what they lost.

THE art of self-protection is one which all animals must practice. It has two extremes of possibility. One is to build a house or shell and retire into it, trusting to its resisting capacity for protection. Such is the theory of a state of siege, such the theory of the armored warrior of the Middle Ages whose suit of enclosing metal frequently weighed one or two hundred pounds. In such a suit a man was either safe or helpless, according to the way the battle went. For quick attack or sudden flight he was practically incapacitated. He gave up the advantages which might be his from the power of free movement for what he considered the greater benefit of comparative safety. At the other extreme in the scale of possibilities for self-protection is the choice of the slightest, most flexible bodily covering consistent with safety. On this theory a man depends for protection on keeping complete freedom of movement. The Indian darting from the shelter of one tree to another counts on fleetness of foot and unhampered power of attack to ensure his safety.

Plants and animals show all the degrees of possible choice between the two extremes. Self-protection, the protection of the fluid life-stuff of their cells, is one of the prime instincts. When plants chose to stay still, they took advantage of the protective possibilities of a heavy covering. They built a heavy outer wall of a thick fibrous substance called cellulose. The whole plant skeleton of stalks and stems is made up of this substance, from which we manufacture paper and cloth. The cactus is a conspicuous example of protection by a stiff, thorny body wall. Even within the moderately thick wall which most plants build, free movement is obviously impossible.

Animals, in general, chose the Indian method

of self-defense. But along the ladder of life development, we find those which, less bold than their fellows, sacrifice some of the joy of free movement for the comforting security of protecting armor. Animals are in constant danger of being eaten by other animals. Each species of animal life is threatened by the food value of its soft, toothsome body to some other hungry species. To be wrapped in a hard and forbidding shell is to have the danger lessened of becoming a luscious and tempting mouthful for some larger creature. It is no wonder that although armor has gone out of fashion for the higher animals, some individual members of several species revert to it, and that whole groups of the lower animals still keep shell coats or breastplates. We do not see such armored monsters as those of prehistoric days lumbering up and down our streets. (See Volume III, page 153.) But we do have the turtle and the snail, the lobster and the crab, the clam and the oyster and other shelled creatures of the water, and the hard-shelled insects of the air, all as truly armored for self-protection as was any mediæval warrior setting forth in battle array.

It is a wonderful shield which the snapping turtle of our picture carries on his back. Even this fierce-looking member of the turtle family with his much decorated backplate is not so completely armored as the common box turtle which has a hinged under shell that enables him to shut himself into his armor as if into a water-tight compartment, there to remain until danger is past. He can hold this closed with a muscular power that makes it a considerable feat for a man with a strong tool to pry it open.

The horned lizard has a tough, leathery skin with spiny scales, plainly to be seen in the picture; but his most conspicuous characteristic is the circlet of horns across his head. These horned lizards are common on the dry plains of the southwestern states and in Mexico. When such a lizard is on the defensive he lowers his head and uses his horns to ward off attack. This lizard is doubly protected, for he has also the power of adapting his color to his surroundings, which is the subject of our next chapter. "Wherever its home," says Harold Bryant, "a

Photo from life by R. W. Shufeldt

HORNED LIZARD FROM TEXAS

This lizard has spines on his tough, leathery skin and a circlet of horns at the back of his head.

horned lizard resembles the color of the substratum so closely that it is practically invisible except when in motion." A lizard living in a region of white sand will be light-colored; one from the black lava belt will be almost black; one from the varicolored mountain districts may show red or even bluish markings. For a creature to have not only armor of a sort and horns but also protective coloring is indeed to be highly favored in the battle of life.

ARMADILLOS

Armadillos — "little armed creatures," by their name — are a curious and interesting survival of a prehistoric family, most of which has vanished from the earth. They range from Paraguay through tropical America to Mexico, and occasionally cross the Rio Grande into Texas. They are the only mammals with such a covering. Armored though they are, they have managed to keep an amazing power of movement by having their scaly coat more or less flexible. An armadillo's skin is the last word in flexible armor. "Armadillos," writes Duncan, "are more or less covered with a hard bony crust, separated into shields and bands, which are more or less movable owing to the presence of special skin muscles. This remarkable covering is, according to Professor Huxley, strictly comparable to part of the armor of the crocodile; and the armadillos are the only mammals possessing such a structure. The shields and bands are formed of many scales. . . . In the most perfectly armored armadillos there are four distinct shields and a set of bands. Of the shields, one covers the head, another the back of the neck, a third protects the shoulders like a great cage, and the fourth arches over the rump like a great dome. The movable bands cover the back and loins, and are between the third and fourth shields. The tail may be invested by complete bony rings and scattered scales. So that these remarkable little animals are veritable armored knights of the mammalian world."

"The ball armadillo is a small and very beautifully ornamented little animal, which has three free central bands and a short tail, with large fore and aft shields. It rolls itself up, on the slightest alarm, so that the great shoulder and croup shields meet, the head and tail fitting in exactly in front, thus closing up the body safely."

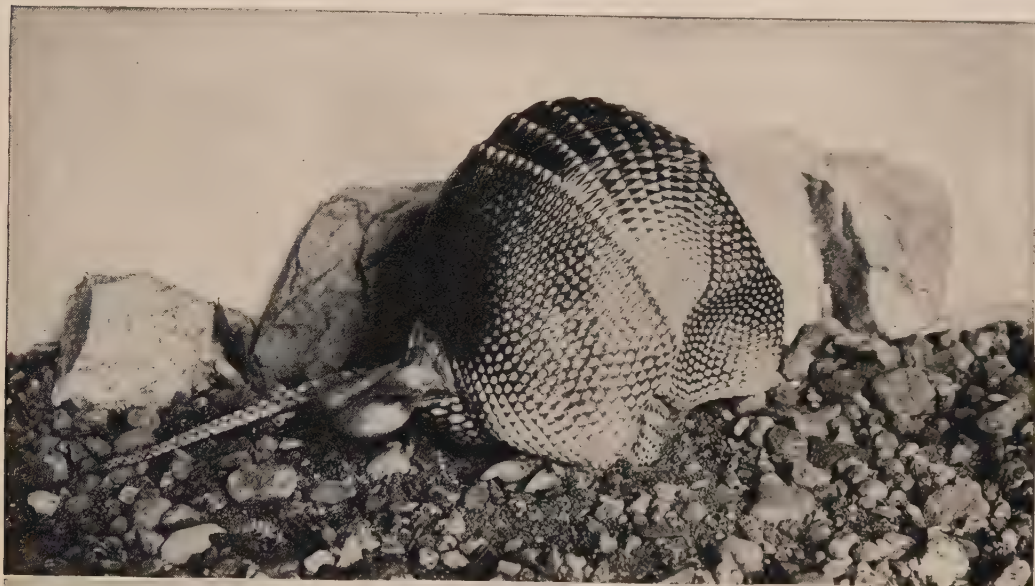
Photo from life by R. W. Shufeldt

ARMADILLO ASLEEP

In this photograph we get the size of the four limbs and the head, which are tucked completely out of sight in the upper photograph on the following page.

The armadillo of our pictures is named "nine-banded" because the large sections of shell are joined in the middle by nine bony rings which hinge together so well that he, too, can roll himself into an armored ball.

It is surprising that the armadillo has been able to keep the advantages of both extremes of self-protection, having an armored coat but one of such superior quality that free movement is possible. So experienced a naturalist as Theodore Roosevelt was surprised at the agility of the nine-banded member of the family. "Armadillos were unexpectedly interesting," he wrote, on his return from Central Brazil,



Photos from life by R. W. Shufeldt

THE NINE-BANDED ARMADILLO

Below, the armadillo at full length, in an attitude of watchful waiting. Above, the same creature rolled tightly in a ball, completely protected by its suit of beautiful, flexible armor. A curious survivor of a prehistoric family.

"because they run so fast." They "may bound off at a run as swift as a rabbit's — as surprising to the observer as to see a turtle gallop away."

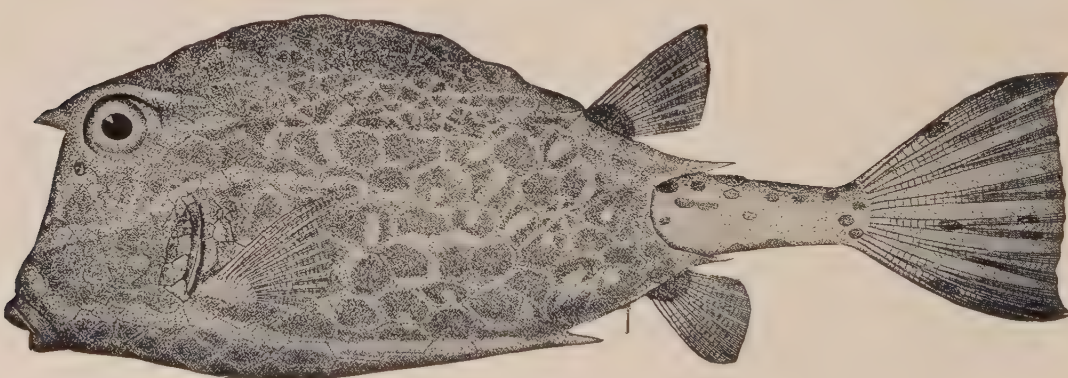
They are said to be good swimmers, and as to their power of burrowing swiftly into the soft ground, it is the subject of comment by every naturalist who has observed them in their native haunts. A man may perhaps come close up to one of the little creatures before it sees him; but the moment it does see him, into the soft ground it throws itself, and before he has reached the spot there is no trace of any armadillo. They are gentle, inoffensive creatures, content apparently with self-defense by the means thus provided for them.

CROCODILES

Crocodiles, with their defensive armor, are of exactly the opposite disposition. Efficiently equipped for self-defense, they are equally well prepared for aggressive tactics. The famous naturalist Saville Kent thought them to be probably the best equipped on both lines of all living animals. "The thick, horny shields," he writes, "quadrangular on the back, tail, and under surface, and adapted in shape to cover the head, limbs, and sides, constitute an almost impenetrable cuirass." Along with this armor go the formidable jaws with their rows of sharp teeth and the powerful tail. "The crocodile's limbs and claws are relatively weak,

A FISH THAT LIVES IN A BOX

This spotted trunkfish spends all his life in an immovable box of bone. See where it ends so that he can move head and tail. (*Shufeldt after Goode.*)



A TRUNKFISH WITH HORNS

This horned trunkfish is a queer-looking fellow, often called a cowfish because his head so much resembles that of a cow. (*Shufeldt after Goode.*)

and incapable of aggressive mischief, but in the long, compressed muscular tail, the reptile possesses a terribly effective weapon."

FISH THAT LIVE IN A BOX

From such a ferocious creature it is a relief to turn to the slow-moving trunkfish of the tropical seas, which spend their lives encased in a bony box of armor which covers the entire body, only eyes, mouth, fins, and tail protruding. It is easy to see in the pictures where the shell "trunk" ends and the movable parts begin. So heavy and thick, says Dr. Shufeldt, is this armor that he has had to give a fairly heavy blow with a hammer to crack it in a specimen with which he was working. The armor is made of many six-sided horny plates and is a beautiful thing in itself as well as a useful cover for its wearer. These trunkfish are queer-looking specimens, especially if like one of those in our photographs they have two long horns reaching out over the eyes. Then they resemble, according to Duncan, nothing so much as a roughly carved head of a cow, with a tail fin standing out like a fan at the rear.

THE DANGER OF RETIRING INTO A SHELL

It looks a feasible and rather attractive scheme of life to carry a shell around with one and retire into it, shutting the door behind, when danger threatens, there to sit in security until such time as one must venture forth for food. But it has not worked well for the animals which followed this tendency. To be imprisoned in a solid sheath is to have one's life so limited that one does not develop high powers. If a creature's movements are obstructed or paralyzed, there is a serious reaction on the creature.

Plants, according to Bergson, fell into "a partial sleep" when they wrapped themselves in a cellulose membrane. They could carry on the necessary functions of their lives without much if any consciousness or feeling. In the same way, he suggests, "the animal that shut itself up in a citadel or in armor condemned itself to a partial slumber." The huge armored monsters of the past disappeared in favor of lithe, active creatures of smaller build. From our own observation we know that neither clam nor oyster, turtle nor lobster, snail nor tortoise are high in the scale of animal intelligence. The race of life was to the swift. In animal development as in human life the rewards were for those that took the risks.

IN OTHER WORDS

"Plants lay emphasis upon immobility, animals upon mobility. Plants in choosing the life of energy-storing were sure of their food, but as a result they became immovably attached to the earth and developed hard parts (cellulose or woody fiber) for the protection of the soft protoplasm, as a result of which protection, stimuli from the external world could penetrate with great difficulty. Owing to this lack of stimuli plants remain very low in consciousness (self-consciousness not meant). Animals, on the other hand, in choosing the more hazardous life of searching for manufactured food, had to remain more or less free, and as a result of this necessity for continued movement could not surround themselves completely with a hard skeleton. Consequently, stimuli from the external world could penetrate with comparative ease, and these stimuli have caused the development of a higher and ever higher consciousness with all its attendant nerves and body organs. All these divergent characteristics have followed as a natural consequence of the first choice." — SHIMER.

COUNT THE CHICKS ON THE ROCKS

Photos by Wm. L. Finley

NATURE PROTECTS HER CHILDREN BY MAKING THEM INVISIBLE

See how plainly the two western sea-gull chicks stand out against the black background. Against the rocks where they are in hiding their color and pattern make them hard to distinguish. There are seven chicks in hiding on the rock of the upper photograph, three against the sand and rocks below.

Copyright, E. F. Bigelow

LEAF HOPPERS, INSECTS THAT LOOK LIKE LEAVES

CAMOUFLAGE IN THE ANIMAL WORLD

The better way—the cloak of invisibility: birds that match their backgrounds, a tiger that matches his jungle, a lemur that hangs from a branch like a lump of fruit, fish that change color.

NATURE has another and a more clever way of protecting its creatures than by forcing upon them a heavy shell armor, of which they must bear the burden all their lives. It makes them safe by making them invisible. In the days of Greek myth there was a pretty story of the way the gods used to throw about the favored mortal whom they wished to protect a magic cloak of invisibility. One moment a man was standing in plain sight of all; the next moment, after he had slipped this cloak over his shoulders, it was to those who looked on as if he were not there. He was there, but he was saved from any danger of attack because he could not be seen and located. Nature uses the same trick to enable its creatures to go about the dangerous business of life successfully. By a marvelous variety of color schemes and patterns it throws around them in the moment of their need a cloak of invisibility. The helpless young sea-gull chicks, shown against a black background in the small oval section of the picture facing this page, advertise their presence to any enemy. But look at them after they have stepped against the background of rocks which is their natural abiding place; even for us who know they are there it is difficult to trace out their outlines. To the unsuspecting eye of a flying enemy they are so like their surroundings as to be almost invisible. By standing motionless against the proper background they have slipped on the magic cloak.

MAN'S USE OF CAMOUFLAGE

Camouflage came to be a matter of popular interest during the Great War, when it became for men, as it had long been for animals, a matter of life or death whether at certain times they were seen by the enemy or not. Those who did not see with their own eyes ocean liners strangely daubed with queer wavy lines and blotches became familiar with pictures of them. Even from a photograph one can get an idea of how this trick might prevent the man in the submarine from being able to locate the exact part of the ship which he desired to strike at a given moment. It is in this type of camouflage that man's work most closely resembles that of Nature. The ship was so colored and shaded that, first, it blended into the waves and sky against which it would be seen, and, second, its otherwise distinct outline — its silhouette, as an artist would say — was made indistinct and confused by conspicuous conflicting lines painted on the middle parts of the ship. The same scheme is practiced by Nature in the color pattern of a skunk. By day his black fur with white stripes makes him conspicuous. But the skunk is an animal that walks abroad by night. The small animals upon which he preys are below him, looking up. To them, as he is seen

through the underbrush against a background of sky, the black patches of fur are of irregular outline, disguising his shape, and the white looks like the sky or light from above. Here is the description an artist gives of the skunk's protective coloring: "As he shambles over a field, with his seeking snout held close to the ground, this white stripe, in the view of the little ground beasts he approaches, 'lets down the sky' through his black head and foreshortened bulky body, splitting this apparition into narrow, un-beast-like halves, which look like sticks or weeds or more distinct bushes or boulders showing above the horizon."

On land man practiced another kind of camouflage. Not only did he put on a uniform which would blend into the dull-colored landscape, he also made objects which would look like part of the landscape within which he might hide. He made an artificial horse which would look like a dead horse stretched on the battlefield, and crept into it for scout observation. He painted a long canvas which would look like an empty road and stretched it over a road on which supply-laden trucks were moving all day long. The enemy observer in the airplane would, from his altitude, notice no difference between this painted road and the landscape in the midst of which it was laid.

Photo by Wm. L. and Irene Finley

YOUNG SKUNK

The black and white markings of the skunk would seem to make him conspicuous; but against a bush background in a gloomy light the white stripe probably looks to the little creatures on the ground like a patch of light, and the outline of the two halves of the furry body is lost in a dark blur.

THE AMERICAN ARTIST-NATURALIST IN DEMAND

To get these effects the military man turned to the artist, and first, it is said, to the American artist. Let me quote from an article which appeared in *Country Life*, by Captain Aymar Embury, 2d. "It is an interesting fact, perhaps not commonly known, that the men whose researches developed the theory on which all camouflage is based were Americans, and that their studies were made primarily as contributions to natural history, although they were painters as well as naturalists. . . . It is fitting, therefore, that military men should have turned to the artist-naturalist for information on camouflage, and should have placed artists in charge of military camouflage."

Captain Embury goes on to point out the difference between camouflage on land and Nature's camouflage, which we are discussing. "There is one fundamental in which Nature's camouflage differs from man's which must be kept constantly in mind in comparing the two, that is, that animals are protected mainly, but by no means entirely, by simulation of color alone, and men by imitation of natural objects in form as well as in color. In other words, most animals are protected by coloring their natural forms, while man hides behind forms which are utterly unlike his own, which may be of shapes built up of papier mâché or plaster of Paris, or which may be natural objects cunningly arranged to afford a hiding-place."

FINDING OUT HOW NATURE PLAYS TRICKS ON US

The man whose name comes to mind when protective coloration is mentioned is the American artist, Abbott H. Thayer. Up to the time when he made his remarkable studies, it had been common to note that animals were protectively colored, that is, that they were so

colored that it was difficult to see them against their natural backgrounds. But when it was said that they were colored "like their backgrounds," there most naturalists stopped. Then Mr. Thayer got interested from the artist's point of view and did a simple experiment. He took a globe, like a croquet ball, and colored it one solid color, green, like grass, and went out and put it down on the lawn of the Harvard Yard. Here was an object exactly matching in color the grass on which it lay, and lo! it was not invisible. Far from it! It stood out plainly for all to see,—a green, solid croquet ball, as different as possible from the grass floor on which it lay. Then he took another ball and painted it dark green on the upper half, shading lighter toward the center, lighter still below the center, and very light indeed where it would touch the ground. He put it on the lawn and walked off. Then he turned around to locate it by his eye, and lo! it had disappeared. He had proved a point which had occurred to him as he thought of protective coloring and was ready, from his artist's knowledge of light and shade, to set forth a truth which would explain why ninety-nine per cent of animals are colored dark on the back, light on the under side, — namely, that they were darkest where they would catch the most light, brightest where they would catch the least. Light comes from above. As it falls on any object it makes a shading of its own. There is a brightest part and then a gradual shading off into a less bright. Nature sets up in its animal coloring a counter-shading, that is to say, an opposite shading. It paints an animal darkest on those parts which will be most lighted by the sky's light, and lightest on those parts which will receive the least light. That sounds reasonable, does it not? But it takes an artist to tell us that this is the trick of coloring by which an animal (or a croquet ball) can be made to disappear into its background. Many birds are light beneath and dark above; from below when they are flying, they are less visible against the light clouds and sky, yet from above they are also less visible as seen against the darker earth with which their dark backs blend.

Light plays tricks with outlines, too. It strikes the outline of an object and makes that object stand out clear and bold. In the evening or at twilight solid objects tend to blend into a soft, flat landscape. The clumps of trees, the boulders, the house on a hill stand out less clearly in a half-light, even though the outline of the hill against the sky may still be very distinct. The light and shade give the effect of solidity. The flounder lying on the sand of the ocean floor flattens into the picture till his outline is lost. Instead of standing out boldly against the light as solid objects, our plump sea-gull chicks flatten against their background. They lose the appearance of thickness.

THE ADVANTAGE OF BEING INCONSPICUOUS

Living is a dangerous and difficult business for the animal world. Creatures are in turn both hunters and hunted. Most creatures are hunters of certain smaller creatures, on which they depend for food, and are hunted by larger creatures, which, in turn, depend on them for their food supply. "On the one hand, Nature fits the hunters to kill enough of the weaker animals to keep themselves alive as a race; on the other, fits the weaker ones to escape so often that their race shall not succumb, that the hunting race cannot overstep its boundaries; that, in short, the even balance between hunters and hunted shall in the long run be maintained." So a naturalist states the rules of the battle of life, into which every creature is drawn. Sight is a chief means of locating either an enemy or the weaker prey. Scent and sound help in the chase. But at the final moment of attack or retreat the sense most relied on is sight. Both hunter and hunted depend on it. At first thought we associate the need of being inconspicuous chiefly with the hunted. Thus may they escape the observation of the hunter. But the hunted are a wary company. They will manage to escape from the enemy which they see afar off. The hunter must be able to stalk his prey unobserved until at the last moment he can pounce upon him. To be so inconspicuous as to be almost invisible would seem at times to be not only a tremendous advantage but an absolute necessity for an animal. And so it is; wherever there is need of it in the animal world this gift of invisibility is bestowed upon the animal, whether he be at the moment hunter or hunted.

THE FIRST LESSON — TO KEEP STILL

The first lesson in self-protection, we may be sure, that every baby creature learns is to keep still. Movement is revealing. A creature may be wholly invisible or inconspicuous against its leafy or sandy background; let it move, and the attention of the observer is called to it. One of the most pronounced laws of the jungle, says Beebe, is that the operation of protective coloration depends entirely on immobility. Ernest Thompson Seton has a word picture of the jack rabbit which is so vivid as to deserve quotation, showing how coloring may be protective at one time and revealing at another.

Photo by M. C. Dickerson

YOUNG JACK RABBIT

His coloring is sometimes protective, sometimes revealing.

"The common jack rabbit when squatting under a sage-bush is simply a sage-gray lump without distinctive color or form. Its color in particular is wholly protective, and it is usually accident rather than sharpness of vision which betrays the creature as it squats. But the moment it springs, this is wholly changed. It is difficult to realize that this is the same animal. It bounds away with erect ears, showing the black and white markings on its back and under side. The black nape is exposed, the tail is carried straight down, exposing its black upper part surrounded by a region of snowy white; its legs and belly show clear white, and everything that sees it is plainly notified that *this is a jack rabbit.* The coyote, the fox, the wolf, the badger, etc., realize that it is useless to follow; the cottontail, the jumping rat, the fawn, the prairie dog, etc., that it is needless to flee; the young jack rabbit that this is its near relative, and the next jack rabbit that this may be its mate. And thus, though incidentally useful to other species at times, the sum total of all this clear labeling is vastly serviceable to the jack rabbit and saves it much pains to escape from real and imaginary danger. As soon as it squats again all the directive marks disappear and the protective gray alone is seen."

A description like this which shows coloring as protective under some circumstances and as distinctly labeling and conspicuous under other circumstances gives us a proper approach to the story of protective coloring. It keeps us from running into the idea that all coloring is simply protective. This was one of Theodore Roosevelt's strong points of controversy. He fully recognized the hundreds and thousands of cases of protective coloration in the animal world, but he rebelled in no uncertain terms against the extreme theory by which all coloring was assumed to be protective all the time.

WHEN NATURE PAINTS

Nature gets its first and simplest effects, as we have seen, by counter-shading. But it does not stop there. It paints on the animal an imitation of its natural background. Let me illustrate. A creature lives on the ground,—a hare or a rabbit. A ground background is made up of mud, grasses, pebbles, tree trunks, branches, twigs, living or dead leaves. Besides the shading from dark to light, the coat pattern may well be a dull gray or brown, more or less mottled, but with no very distinct picture patterns. There are really no gaudily colored ground-living mammals. But take a tropical bird. It lives in a world of foliage and flowers. If it were of a solid, sober color, it would stand out as a dark patch against the brilliant colors of its gorgeous background. It is one of the lessons

FLYING LEMUR AT REST

As the flying lemur hangs from the branch of a tree, he looks like a great tropical fruit. (*Shufeldt after Goodrich.*)

we must learn that a bird or an animal which looks conspicuous against a plain solid-color background may not be conspicuous at all—almost surely is not conspicuous—in its native haunts. Birds of Paradise are excellent examples. In a museum they are showy and conspicuous. In their native woods, which are overflowing with every possible variation of color and every changing effect of light and shade, it has been the testimony of collectors that it is hard to locate them. "Leaves and stems and trunks and branches, vines, fruits, and flowers, shade and sunlight — all mix and overlap and intertwine in the most bewildering way. Amidst, against, this intricate tangle . . . a bird so adorned with grotesque plumes and bristling 'hay-stack' tufts of superadded feathers as to have lost almost all semblance of his simple bodily form, would be almost insured against detection as he sat or moved in such a forest maze." Brilliantly changeable iridescent colors are found to be very concealing. In a world of moving leaves and flowers, with dissolving colors everywhere, the change between most brilliant shades is itself concealing in that it kills the effect of outline.

STRIKING AN AVERAGE

No bird or animal matches its background perfectly. But Nature has perfected typical or average backgrounds that will serve for many scenes. Animals actually wear on their backs a sort of compound picture of the regions in which they live. If they lie against green leaves, they have a kind of average green-leaf light and shade background, like that of the tree frog in Volume III, facing page 254. Shore birds carry a finely drawn pattern of beach-sand and pebble markings, or so it seems when one contrasts them with the water birds which tone so softly into a background of sea and sky.

Besides the near patterns there are interesting examples of light and shade patterns. Our tiger, drawn for us as he emerges from the jungle,

AS HE SPREADS HIS LIMBS

Here is the creature which had tucked himself so neatly away for the upper picture. (*Shufeldt after Goodrich.*)

is a striking example of matching his surroundings. His black stripes match the shadows thrown by the heavy jungle grass and reeds, his tawny coat is not far different from the orange stems of the giant bamboo or even the drying jungle grass as it lies on the ground. Or, as another naturalist has described it, "his general color is that of the interiors of bushy thickets, reed-beds, the underwood of the loftier jungle; while his stripes picture vertical stems and slender trunks in shadow, and also the sun- or moon-engendered shadows that such plants cast upon the ground in opener places. . . . Nothing short of a perfectly plain background can neutralize its power." The same writer, who speaks of "the terrible inconspicuousness of the tiger in its native haunts," says: "A leopard or a jaguar stretched out on a lofty branch, lying in wait for monkeys, his deceitfully counter-shaded and spotted coat dappled into still further indistinctness by the very shadows and sun-spots it counterfeits, must be about the most insidiously inconspicuous of hunters. . . . The brilliant crossbands of the zebra cut their wearers all to pieces and look exactly like the stripings of the lighted reeds across their shadowed background."

Photo by Wm. L. Finley and H. T. Bohlman

YOUNG KILLDEER HIDING

This very unusual photograph of a plover in hiding shows the value of a "ground-pattern" coloring. A few feet farther away it would be hard to locate the bird.

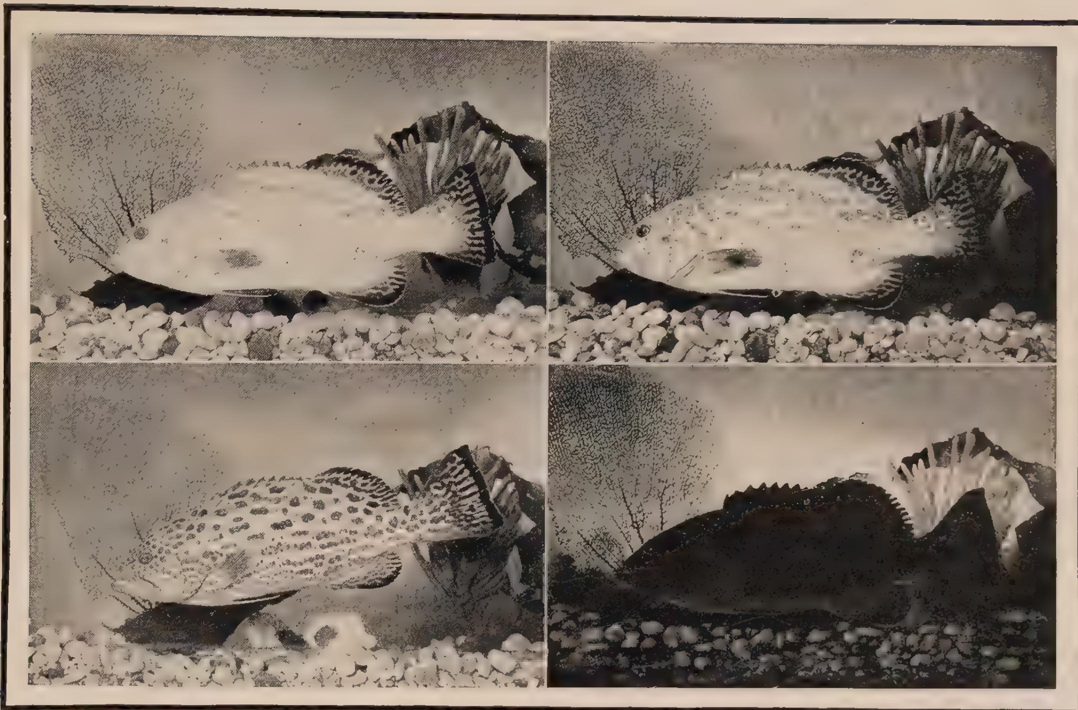
So we learn that what may seem to us the most revealing of color patterns are under certain conditions the most concealing. The brilliantly colored fish has the tints of the gorgeous plant life of the sea. If in addition to this safeguard he has the power to change color at will to match the better his surroundings of the moment, a power which many fish and a few higher animals possess, he is doubly safe.

CAMOUFLAGE AND MIMICRY

Along with camouflage goes mimicry. The hanging lemur of our pictures is practicing this. He is visible in both pictures, — very much so; but in one he looks like a tropical fruit as he hangs from the branch. He is gaining protection by looking like something different from what he is. He is practicing a species of deception on his enemies. We might say that he is deceptively visible — and that is mimicry, while the sea-gull chicks are practically invisible, and that effect is gained by concealing coloration. Both are often included in the term camouflage.

Throughout the book we shall come upon examples both of these and of many other devices by which an animal is protected or protects himself. We shall read of weapons of offense and defense, of poison gases and inky smoke screens; we shall learn of partnerships for mutual safety and comfort, and of colonies with fighting members; we shall see how eyes and ears and noses act as sentinels for their possessor. But of all the means which Nature has devised for the protection of its creatures, none is more interesting than this magic cloak of invisibility which it throws around them. To

TIGER EMERGING FROM THE JUNGLE—A HARMONY OF COLOR



Photos by A. C. Eldredge

AS A FISH CHANGES COLOR AT WILL

By a curious shifting of color cells many fish and a few animals can change color rapidly in response to outer conditions or inner excitement. The body of the yellow-fin grouper which "posed" in half an hour for these four photographs is normally a delicate pearl gray with large patches of darker gray, and with edges of fin and tail an intense black, as shown in the first photograph (upper left). He was hungry, and his body flushed to a tint approaching scarlet with red-brown spots (upper right). The water in the tank was disturbed, and he showed his excitement by a darkening of the body and a brightening of all color spots (lower left). He hid near bottom against a dark brown stone (lower right) and matched it perfectly.

fight successfully and win is a crude method of self-protection as compared to melting unseen into a background which waits to receive and shelters.

The possessor of the magic cloak gives up no other power of self-defense. He can watch from his ambush; he can probably flee if safety lies that way; he can fight if found. Partial invisibility is, however, his first refuge; and often a sufficient one. If it fails, he can adopt more aggressive measures.

"Any device that a plant or animal has for getting on in the world interests us; it brings the lower orders nearer to us. We have our own devices and makeshifts, and we like to know how it is with our near or distant kin among the humbler orders." — John Burroughs.

"The living world is a very serious game of hide-and-seek, in which nearly every adult animal and those young ones that are not hidden or protected by their parents must join. The penalties are severe: those that are caught are eaten, and those that fail to catch starve. Animals may hunt their prey by scent; but there nearly always comes a critical final moment when they must be able to see the object on which they are to pounce."—Mitchell.

Photo by R. W. Shufeldt

FLYING SQUIRREL

THE CYCLE OF LIFE

How the sun rules the world, how the plant stores sunshine, how the animal gets it — how the animal depends on the plant and the plant on the animal.

THIS is a story of Life in large letters, of its big sweep as it swings through the plant and animal worlds. It is as if you were carried to a mountain top and shown the plan on which the whole living world is run. Even when the story seems to take you down from the mountain top to the familiar things of every day, to the plant in the field and the animal in the pasture, you will still keep the thought of yourself as standing off and looking at them as parts of the great framework of the living world.

THE SUN THE SOURCE OF ALL ENERGY

First we look up from our mountain top at the sun. Priests of olden times used to lead their people forth to greet the rising sun as the source of all physical blessings. Though we are not sun worshipers, yet the scientist of to-day could join hands with the priest of long ago in giving to the sun honor as the source of all that makes the earth a possible and fit place for life. Though we repeat it again and again to ourselves, we never quite master the amazing fact that all life on the earth depends on this immense globe of matter ninety millions of miles away. The sun is the storehouse from which comes the energy that makes life possible and keeps it going. It is not simply that the sun gives forth light and heat which keep the earth in a fit state of warmth and comfort for the plant-animal world to go its way. The plant-animal world is literally run by the energy which comes from the sun, chiefly in the form of light and heat. In every movement that we make we are drawing upon energy which came originally from the sun.

Again and again in this book on THE WONDER OF LIFE, we shall come back to the subject of the sun's energy. This time we ask you to take it for granted that in a mysterious way the sun sends out from itself across the millions of miles which separate it from our planet a never-ending supply of energy which is at the basis of all our motion, our power, our work. No life process could take place without it. With this fact at the back of our minds, let us trace together the wonderful circle or cycle of plant-animal life which has its source in the sun.

HOW IS THIS ENERGY CAUGHT?

Picture sun energy pouring in on the earth in sunlight. How can it be caught? How can it be imprisoned and transformed to make "the wheels of life go round"? If there were no plants, this energy could not, as the world is now arranged, be caught. Animals alone, man alone, would stand helpless before this problem. Their cry for the energy required for them to carry on their lives would be like that of the Ancient Mariner, dying of thirst though floating on the ocean, who cried out,

> "Water, water everywhere,
> Nor any drop to drink."

Green plants can catch it and set it to work. In their leaves are grains of a green coloring matter, which can act as a "go-between," as a "transformer" between the unlimited supply of energy pouring in on the earth from the sun and the waiting world which needs that energy. The story of this green miracle-worker has a chapter of its own, "At the Sign of the Green Leaf." Just now what we are tracing is the sun's energy. As it comes in contact with the green leaves of plants and trees, they catch it, imprison it, and transform it. How? First, by splitting up air by its means.

It is a commonplace of science that air is made up of three gases,—nitrogen, oxygen, and a compound called carbon dioxide. At this moment it is the carbon dioxide in the air with which we are concerned. This carbon dioxide is known to chemists as CO_2, which is only translating into letters and figures what we might read out of the words, namely, a single amount of carbon (C) to a dioxide or double amount of oxygen (O_2). (It is amazing how words and signs which look very learned and puzzling prove often to be simple when you walk right up to them and challenge them to tell you what they mean.) It is in the splitting up of this carbon dioxide that sun energy comes into play.

A BOY AND A SLING

What do we mean by this "energy" of which we speak so familiarly? It may be a new word to you, as it is used in this book; but with the idea itself you are entirely at home. Let us take a common illustration and tell about it in terms of energy, as the scientist would interpret it. Matter is that of which the world is made; it is all about us. We ourselves, so far as our bodies are concerned, are made of matter. A boy throws a stone. The stone is "matter"; in throwing it he is "moving matter." To do this he uses energy. When we perform any act, we are moving matter. Told in the simplest terms, everything we do in life, on the physical side, is simply moving matter from one place to another. We walk: we are moving our bodies. We eat: we are moving food and moving our arms, jaws, tongue, etc., in receiving food. We build houses, we manufacture, we do a thousand and one things. In all these acts we are moving matter and we are moving it by means of energy.

Where does this energy come from? In the case of our own bodies it is not so simple to explain as it is in the case of something outside ourselves. Let us suppose that the boy has a sling for his stone. He draws back the elastic band of his sling. In so doing he pulls apart molecules that want to stay together. The moment he lets go, the elastic will snap together; the molecules will not stay apart an instant longer than they must. The boy applied energy to stretch the elastic. For the moment that energy which he applied was "stored" in the stretched elastic as he held it taut. When he let it go, just the amount of energy he had exerted to stretch it was released. The sling is a machine for doing work, — for moving the stone. The boy is its source of energy. In a similar way, all the moving, acting creation — every plant and every animal — is fitted to do work, provided it has energy applied to set it going and keep it going. Without this energy the world would be still; there could be no movement. With it all the acts of living are performed with a beautiful regularity. The boy supplied energy for the sling. The sun supplies energy for the whole world. The green leaves "catch" and store it. The energy is "caught" in the process of splitting up air, or rather, in splitting up the carbon dioxide which is in air.

SPLITTING UP AIR

To split up a molecule of carbon dioxide gas into its two elements, carbon and oxygen, may be a simple matter in a formula or in your

mind. But if you tried to do it in a laboratory, you would find it far from easy. If carbon and oxygen were persons instead of invisible atoms, we should say that they clung to each other so closely that they could hardly be pried apart. But along comes the sun energy. Caught in the green leaf, it can take these two and force them apart as if such a task were a mere nothing. It pulls the carbon away from that oxygen so quickly and so quietly that you and I, looking at a sunlit leaf, never suspect that any force is being exerted. The oxygen it lets go; this the leaf discharges into the air as waste. The carbon it keeps and recombines with water (received from the air and the soil) into a food product. Later we shall find out more about this food. At present we are thinking only of that carbon, caught in the plant and imprisoned in a food product, but still wanting its oxygen which is out in the air.

A BROKEN PARTNERSHIP

If we were telling this as a fairy story, we should picture carbon as an imprisoned fairy, and oxygen as a wandering spirit trying to get in at every closed door and through every crack and cranny to find its lost mate, carbon. Although these atoms are not fairies, they are swayed by a law as strong as any spell which could ever be cast in a fairyland. Whenever, wherever oxygen finds that carbon, no matter with what other elements the carbon happens to be combined at that moment, enough of the carbon will "forsake all others" and rush to the oxygen to form once more the old partnership, the one-to-two compound, carbon dioxide.

Also — and here we come back to our energy story — there will be released at the moment of their coming together just the amount of energy which was needed to pull them apart. That is a bit harder to understand, is it not? Let us come back to our small boy with his sling. The energy he applied in stretching the elastic was stored in the elastic as it was held taut. Whenever he should let it go, exactly that amount of energy would be released. He wished to make use of that energy to shoot a stone across the street. So he placed a stone in the sling in such a position that when the elastic snapped back, the energy released shot the stone out into the air. To return to our carbon and oxygen. The two were separated by the exerting of energy — sun energy. Wherever they come together again, it will be the same story as that of the molecules in the stretched elastic which were allowed to come together again when the elastic sprang back. A certain amount of energy was required to pull the carbon and oxygen apart in the green leaf; an equal amount of energy will be released at the point where they come together again and can there be set to work. The secret of using energy is to be on the spot with machinery that can be run by it when it is released. That is what occurs in the plant-animal cycle.

THE PLANT-ANIMAL CYCLE

We have been talking of laws and of energy and of other general things long enough. Now let us come down to a familiar scene, as shown in our picture, to a green field, a vegetable garden, two men, and two cows. Within the bounds of that simple scene is being carried on the most marvelously efficient scheme for the storing and the releasing of energy that could ever be conceived. Here are plants so built that they need carbon for their processes; here are animals so built that oxygen is for them a necessity. Here is carbon dioxide in the air, and here is energy pouring in from the great storehouse of the sun. If you were trying to figure it out for yourself, like an example in arithmetic, how could you do it better than to suggest that it would work well if the plants took from the air the carbon, which they could use, and gave back the oxygen, which they did not need; then that the animals took from the air the oxygen which the plants had released. It would sound ideal, would it not? That is exactly what does happen. Sun energy makes it happen by pulling the carbon and the oxygen apart. The plants promptly appropriate the carbon, giving back to the air the oxygen. The animals as promptly appropriate the oxygen. When the animal eats the plant as food, it takes in the carbon; when it breathes, it takes in the oxygen. The two rush together in the animal body, and energy is released. They come together with such eagerness that they get all heated up and warm the animal in the process. Let us follow

THE MARVELOUS CYCLE OF LIFE

PERPETUAL MOTION—NO WASTE OF MATERIAL

A familiar scene, shown in the center, split up into six enlarged sections to show the story of life as it is lived in the plant-animal world. In I the sun is sending its energy to the earth in light and heat. II is a closer view of I, showing how the plant by means of sun energy takes from the air carbon dioxide (CO_2), holds the carbon, and gives back the oxygen. In III the animal eats the plant, thus getting the carbon. In IV the animal breathes in oxygen. Carbon and oxygen meeting in the animal's body give off the energy by means of which the animal can keep warm, can move, can live. Then the animal breathes out this carbon and oxygen in carbon dioxide (CO_2). Thus it gets into the air for the plant to catch it again. Such is the story of plant-animal life as depending on the sun. In V man eats both plant and animal food. He, too, gets carbon. He, too, breathes in oxygen. They meet in his body. He lives and moves by the energy given off at the point of meeting. In VI he, too, breathes out carbon dioxide (CO_2). The plants take it in and the cycle begins again.

this out in the picture. To show the plant-animal cycle of energy the artist has divided the scene (shown in the center) into several scenes, each a part of the whole.

In I we have the sun sending its light and heat, its energy, to the earth. The green plants are there, ready to use it; the carbon dioxide (Co_2) is in the air surrounding the plants, ready to be taken in and split up. II is a "close-up" of the same scene, the plants in the sunlight taking in carbon dioxide, splitting it up by the sun's energy, keeping the carbon imprisoned, letting the oxygen go back into the air. In III, we begin the animal stage of the cycle of energy. The cow is eating plants, taking in as food the carbon which has been made up within the plant into stored food products. But, as we are reminded in IV, the cow is not only eating, she is breathing. Here we are getting toward the completion of the cycle. When an animal breathes it takes in oxygen from the air into the lungs. Oxygen, you remember, is the wandering member of the partnership, carbon dioxide. When an animal eats plant food, it has taken in carbon. This carbon is carried as food through the cow's body to build up and repair her living cells. Now comes the oxygen, breathed into the lungs and carried by the blood all over the body. Every one of us can see what happens. The oxygen finds the carbon in the living cells of the animal body. The two are reunited.

What was to happen when the broken partnership was re-formed? The same thing that happened when the small boy loosed the elastic band, — energy was to be released. It happens here. Energy is released, and by that energy the cell machinery all through the cow's body is set at work and kept running, and the cow moves, eats, lives, keeps warm.

There is one more step in the cycle. When the two come together, the gas carbon dioxide is formed. For this the cow has no use. It was the energy alone which she needed. So she breathes this carbon dioxide out into the air. And there it is in the air, ready to be taken into the plant and split up again. See the economy of Nature's scheme. The oxygen thrown out as waste by the plant finds in the animal its carbon. The two are breathed out into the air by the animal as carbon dioxide for the plant to take up again. And meanwhile in splitting them apart energy has been caught, and in their coming together energy has been released and the machinery of life kept going.

WHEN MAN COMES IN

In the story of the plant and of the cow (a plant-eating animal), we have the simplest form of the plant-animal cycle. But the animal does not give out all its carbon. Some it stores in flesh and fat. In V, man, a meat eater, comes into the story. He eats vegetables (plant food) and gets their carbon compounds into his cells; he drinks milk (animal food) and gets its carbon compounds into his cells; and he eats meat (animal food) and gets its carbon compounds into his cells. Meanwhile, like all living creatures, he breathes in oxygen. The blood takes it up and carries it all over the body. At the right moment the carbon of the food unites with the oxygen from the air. Energy is released, and the cell machinery uses it. The man can live, move, eat, walk, run, on that store of energy. Food is, as has been well said, "man's storage battery, charged by the sun"; oxygen, obtained by breathing, has "discharged the battery." As you see in the picture (VI), while the man was breathing in oxygen, he was breathing out carbon dioxide into the air, whence the plants would take it. So the carbon-oxygen cycle is complete.

HOW THE LIVING WORLD IS KEPT GOING

All that is required to keep this movement going is energy, more energy, new energy from the sun. Not more carbon, not more oxygen, for these are kept moving round and round in the cycle—only the energy to keep them going. This the sun supplies in abundant measure.

Such is the big, unwasteful, ever revolving plan of Nature. Look at the world from the mountain top of this knowledge. See what a wonderful scheme it is. The energy for all life processes is supplied by the simple device of pulling carbon and oxygen apart in plants, keeping them apart in food, and allowing them to come together again in animals. With such simplicity and economy of effort does Nature manage its living creation.

Photo by S. Leonard Bastin

GIANT LEAVES FROM THE TROPICS (*Gunneras*)

AT THE SIGN OF THE GREEN LEAF

A miracle of life — how the green leaf makes lifeless matter live.

WHEN a manufacturer has perfected a process by which he turns raw materials into a desirable product, he selects a trademark, some distinctive sign or symbol by which this process or its product may be indicated. He then causes this trademark to be posted wherever process or product appear, until in the minds of the public a sight of the trademark instantly suggests the whole story.

NATURE'S TRADEMARK

Green, as it appears in the green leaf, is Nature's sign of the most wonderful process which takes place on our planet. It is the symbol of Nature's constant transformation of a lifeless world into a living. It is the trademark for a chain of millions and billions of plant factories where this process of manufacture is going on.

A manufacturer keeps his process secret lest competitors duplicate his methods and steal his trade. Nature has no fear of competitors. Its processes are mysterious and secret only because of our lack of understanding. Lately we have come to know more of this fundamental process for which the green leaf is the site and its color the symbol. We have spoken in the preceding chapter of some phases of this green-leaf process as a part of the plant-animal cycle of life. Let us begin now and trace it as a process of manufacture, as definitely as in Volume II we traced the manufacture of shoes or soap. Only by making this matter-of-fact comparison with our human manufacturing processes can we see how unique this green-leaf process is.

WHAT IS ACCOMPLISHED IN THE FACTORY

The green leaf is essentially a food factory. It stands surrounded by a lifeless world; it is part of a living, hungering world. Earth, air, and water — these are its raw products. With them as raw products the human or animal machine would be powerless to carry on any life processes. Not so the plant. It has the secret of extracting the elements desired from the earth, the air, and the water, and of recombining them into food. This food supports the life of the plant, supports indirectly the life of the animal, including man, and in its natural secondary forms of wood and coal enables man to carry on his multifold activities. The green-leaf factory alone can "make food out of that which is not food," as Dr. Coulter has well said. In short, the green-leaf factories supply the products which are the basis of all our activities.

THE FACTORY

Let us consider our factory, the green leaf, or, broadly speaking, any green tissue of the plant. Of these the leaf is the chief, for it is built to give the greatest extent of thinly spread green tissue. That this is a factory of no mean size you will admit when I tell you that the leaves on a medium-sized maple tree, if spread out side by side, would cover half an acre of ground. In other words, a maple tree is a factory covering half an acre.*

Each division of this establishment, each leaf, has many, many tiny rooms or cells. These cells are lined with a thin layer of protoplasm, the precious life-stuff of which we are to talk later; and besides that layer there are within each cell, close up to the living wall, tiny grains of a thicker protoplasmic substance colored bright green. It would be easier for you to remember the names of these grains and of the coloring matter in them if you knew the Greek language. The green coloring matter or dye is called *chlorophyll*, from the Greek word *chloros*, meaning "light green," and *phyllon*, meaning "leaf." So, literally, chlorophyll means "green leaf." It is the word used to describe the green dye which colors the tiny grains of protoplasm floating in the cell. The granules themselves are called *chloroplast*, meaning literally "green protoplasm." So whenever you see the word "chlorophyll," — and you will see it often, for this is one of the most important substances in the world, — say to yourself "green-leaf stuff." Then you will have its story.

HOW THE MACHINERY WORKS

Here in these little grains of protoplasm colored green you have the machinery of the factory. Gray or colorless protoplasm can do wonderful things when it is animated by the touch of life; but it cannot do what this chlorophyll stuff in the tiny grains can do, for it cannot catch and hold for use the power here set at work. Idle machinery without power to run it is as impotent as a steam engine with no fire under the boiler or a trolley car with no electric current flowing through it or an automobile with no gasoline.

The power for the leaf factory is, as you know, sunlight. To understand how this power is caught and "turned on," I want you to go back to something you learned long ago, in Volume I, about light. Take down Volume I from your shelf and open it at the color plate facing page 100. Light is pictorially shown coming from the sun. The red, green, and violet rays are used (in diagram) to stand for the broad color band of the spectrum. The color of an object, as we are reminded by this diagram, depends on what it does with the sunlight which falls on it. It may absorb all the rays and look black; it may absorb none of the rays and look white; or it may absorb some rays and reflect others, and so be red or green or blue. The color as we see it depends on those rays which it does not absorb, but which it reflects to our eyes. The leaf is green because, while it absorbs the red and violet rays from sunlight, it does not absorb the green. The green rays it turns back or reflects; they give the trademark for its factory process.

Now a great many other things in the world besides the green leaf look green. The frog in the color diagram is green. But the frog's skin is not a food factory. The red and violet rays are absorbed by it, but they are not set at work in it. The great distinction of the green

* Half an acre is almost a third of a city block, as such a block is bounded by four streets, or it is a piece of land equal to three or four suburban house lots.

leaf over other green objects is that it not only holds the red and violet rays but also sets them to work to make food. Chlorophyll alone, of all the substances in the world, can turn this trick. It does it by the life-stuff in its tiny grains. *Why* chlorophyll can do this when other substances cannot, we do not know. *What* it does and *how* it does it, we do know. By setting to work the sunlight which it absorbs, it gains the needed power to run its food factory.

WHAT IS THE WORK TO BE DONE?

By this time you have become accustomed to the idea that the world is made up of a small number of elements, like carbon, hydrogen, and oxygen, put together in millions of combinations to make all the things with which we are familiar. So you will not be surprised to know that this power is set to work to pull elements apart and put them together. It is the machinery in the leaf which takes the carbon dioxide (CO_2) received from the air, and the water (H_2O — which is to say, two parts hydrogen to one part oxygen) received from the soil, and pulls them apart. The carbon dioxide it splits up into carbon (C) and oxygen (O_2). The oxygen is thrown off into the air; the carbon is kept for re-combination with the hydrogen and oxygen of which water is made up. Having on hand these three elements — carbon, hydrogen, and oxygen — the factory turns out a product called "grape sugar," put together in the proportion of six parts of carbon to twelve parts of hydrogen and six parts of oxygen, or, by the chemist's formula, $C_6H_{12}O_6$. From this grape sugar are made, in a series of chemical changes, sugars and starches, which are the first and simplest foods of the plant and of the animal. (They are simply combinations in different proportions of the same three elements, — carbon, hydrogen, and oxygen.) Grape sugar, which is the basis of all food, is the original product of this plant factory, sugars and starches being its secondary products, and oxygen, thrown off into the air, its waste product.

How important this factory process is you can judge when I tell you that I read a learned article lately telling how some astronomer thought he had discovered chlorophyll in the spectra of Uranus and Neptune, those far-off planets swinging on the edge of space. You and I would not have been wildly excited if we had been told that there was the barest possibility of the existence of chlorophyll on a planet thousands of miles away, but this astronomer was. Chlorophyll, he said, lies at the basis of life in our world. If there is chlorophyll anywhere, there may be green leaves, vegetation, and if green leaves possibly animal life. To his trained mind, if other conditions were favorable, a sight or suggestion of chlorophyll, of "green-leaf" substance, meant a living instead of a lifeless world.

A DAYLIGHT FACTORY

Notice that the green-leaf factory is a daylight factory, its hours strictly limited by the sun's hours above the horizon. No night shifts here; stoppage of manufacture when the power is turned off!

Run the story over again to be sure you have it: the green leaf is the factory; the cell is the room where the work goes on; the colored protoplasm grains within the cells are the machinery; the power is the sun's rays; the chlorophyll has the power to reflect away the green rays but to keep the rest; the life-stuff uses those rays to supply energy for its work of taking apart carbon and oxygen — a tremendous task — and of re-combining the carbon thus obtained and the hydrogen and oxygen of water into grape sugar, a new CHO combination which is soon transformed into starch and sugar, the basal foods of the world.

What would you call such a factory process if you had to name it? Scientists have given it a beautifully clear name which I think you will like when you hear it. Because this is a daylight factory, dependent on sunlight for its power, they have named the manufacturing process "putting together in the presence of light," or, as they borrow the Greek words, *photosynthesis*, *photo* being the word for "light" (made familiar in the word "photograph"), and *synthesis*, which means "putting together."

"Putting together in the presence of light" — that is the process for which the green leaf is the factory. Whenever you see Nature's trademark, a green leaf, cherish its beauty, admire its texture, but remember, too, that as it

seems to sway idly in the sunlight, it is in reality a busy factory, making possible by its product all the work of the world. Remember that the green plant is the only independent organism in the world, for it alone can take from the air and the earth lifeless matter and transform it.

These are thoughts to think when you look "At the Sign of the Green Leaf."

IN OTHER WORDS

When we are dealing with great vital facts of the universe, it is stimulating to get different points of view and different phrasings. After the main argument has been presented in our own simple stories, we therefore present the same facts in the forceful words of leading authorities, each of whom contributes something to the discussion.

"There is more than poetry in the statement that every human act is a transformed sunbeam." — GRUENBERG.

"Vegetables alone gather in the solar energy, and the animals do but borrow it from them, either directly or by some passing it on to others. How then has the plant stored up this energy? Chiefly by the chlorophyllian function. . . . The process consists in using solar energy to fix the carbon of carbonic acid, and thereby to store this energy as we should store that of a water-carrier by employing him to fill an elevated reservoir: the water, once brought up can set in motion a mill or a turbine, as we will and when we will. Each atom of carbon fixed represents something like the elevation of the weight of water, or like the stretching of an elastic thread uniting the carbon to the oxygen in the carbonic acid. The elastic is relaxed, the weight falls back again, in short the energy held in reserve is restored, when, by a simple release, the carbon is permitted to rejoin its oxygen." — BERGSON.

"The photosynthetic grape sugar formed in green leaves in the light is the basal food of both plants and animals. This sugar is therefore one of the three most important substances in organic nature, chlorophyll and protoplasm being the other two." — GANONG.

"Green plants have been characterized as the mediators between life and death." — COULTER.

"The general scheme of Nature is to cover the whole world with green, so that every ray of sunlight may find a working leaf to welcome it. Nature abhors bare rock, barren sand, and empty water, and never ceases to try to bring it under that beautiful covering of green plants and active vegetable life which supports both man and animals." — ELLIOTT.

"Between earth and man arose the leaf. Between the heaven and man came the cloud. His life being partly as the falling leaf, and partly as the flying vapor." — RUSKIN.

"For what infinite wonderfulness there is in this vegetation, considered, as indeed it is, as the means by which the earth becomes the companion of man — his friend and his teacher! In the conditions . . . in its rocks, there could only be seen preparation for his existence; . . . but vegetation is to it as an imperfect soul, given to meet the soul of man. The earth in its depths must remain dead and cold, incapable except of slow crystalline change; but at its surface, which human beings look upon and deal with, it ministers to them through a veil of strange intermediate being; which breathes, but has no voice; moves, but cannot leave its appointed place; passes through life without consciousness, to death without bitterness; wears the beauty of youth, without its passion; and declines to the weakness of age, without its regret.

"And in this mystery of intermediate being . . . most of the pleasures which we need from the external world are gathered, and most of the lessons we need are written, all kinds of precious grace and teaching being united in this link between the Earth and Man: wonderful in universal adaptation to his need, desire, and discipline; God's daily preparation of the earth for him, with beautiful means of life." — RUSKIN.

3 6 14 28 70

A LEAF AS OLD AS ITS VEINS

The older a plant, the smaller the areas between the veins. Dr. Harris M. Benedict, of the University of Cincinnati, to whom we are indebted for this photograph, has made the interesting discovery that by examining with an ordinary hand lens the leaves from a vine its age can be approximately determined. For instance, the five successive leaves in the above photograph were from vines three, six, fourteen, twenty eight, and seventy years old, the meshes of the network becoming finer as the vine became older.

A ROBBER PLANT AT WORK

Photos by S. Leonard Bastin

ROBBER DODDER—A PLANT WITH NO GREEN LEAF OR ROOT

1. The plant comes up from the ground and sends out a feeler. 2. It hits a clover stem. 3. It twines around the clover. 4. It sends out two new feelers. 5 and 6. It has gained a strangle hold, has given up all connection with the ground through roots, and is sucking its food from the clover, which it will probably kill.

STEALING A LIVING

Plants that go on strike, how they rob and kill—the largest flower in the world, when and where it was found—parasites, how they help or harm man.

PLANT society, like human society, has members which prey upon others for a living instead of going to work to earn it for themselves. But there is this important difference. In the plant world a child born into a robber family has no choice but to be a robber if he is to live at all. There used to be in India a robber caste, a class of people who were robbers, whose ancestors had been robbers, and whose children were expected to be robbers. Until the missionaries came and taught that each child had a right to choose an honest means of livelihood, it had been taken for granted that any child born into the robber caste would be a robber. In plant life the caste idea is true, for long before the plant child was born his chance to earn an honest living independently was taken from him by lazy ancestors who found it easier to live by stealing than by working and so failed to make use of their working powers and organs. Nature never carries on a part which is not used. So gradually as these plants of long ago failed to work, the parts by which they might have worked were taken from them, and there was forced upon their remote descendants, the plants of to-day, either prompt starvation or a life of theft.

IF A PLANT HAS NO GREEN LEAVES

The part of a plant which makes it the most independent organism in the world is its green leaf. By means of its chlorophyll the plant can catch the sun's energy, use it to split up the lifeless elements of the air, the earth, and the water, and so set in train a process of food making. The food thus made it can pack about its tiny seed, so that the baby plant will have a good supply of nourishment until it can set to work in its turn to get food for itself. The robber plant has no leaves and can therefore do none of this work for itself, but must get its elements of nourishment from some working, leafy member of plant society.

HOW ROBBER DODDER MANAGES

Take the twining robber dodder of our fields, shown on the opposite page, as an example. Its seed, developing in the ground as if it were to grow into a plant of the usual type, has no food provision but produces a mere thread which it sends up into the air. That thread sweeps about in the air for two or three days. If it touches no neighboring plant it dies. If in the course of its turnings it touches a suitable plant its life is saved, though at the ultimate expense of the life or at least the normal growth of the other plant. Here dodder in reaching out finds a clover stem and begins to twine about it, first making its hold secure and then driving into the clover rootlike tubes through which it sucks the life juices of the plant. Round and round it twists and winds and ties itself, flourishing in the abundance of good living thus "on tap," until it has a strangle hold on its victim. In the meantime it has long since given up its good honest connection with the earth which bore it, its root stem having been discarded and having withered away. So if you came upon the plant (here photographed), you would not be able to find its root. It would appear to be simply a tangled mass of yellowish thread wound in and out of the plant, and producing in its due time a cluster of pale white flowers, almost bell-shaped, which help to identify it as a degenerate branch from the good old parent stem which also produced the honest and hard-working bindweed and morning-glory. "Devil's thread" the peasants call it, doomed to this life of theft because its remote ancestors neglected to use the leaves and the chlorophyll (of which slight traces still remain at birth) with which they might have

earned an honest living and taken an honorable place in plant society.

PARASITES

Such plants are called "parasites" because, like the Greek flatterers of old who bore this title, they "sit at the table of another." Many of them do not even pretend, however, to pay their way by pleasant attentions as did the hangers-on of classical days. If they have no leaves they are entirely dependent upon the plants on which they prey. Some, like the mistletoe, are less abject in their dependence. Its sticky seeds are carried to the tree on the feet or feathers of birds and there gain a foothold for life, sending down rootlets into the host. But while the mistletoe treats the tree as the usual plant would treat the soil in which it grew as a source for water and minerals, it makes its own food by the chlorophyll of lemon-green leaves, possibly returning to its hosts in the winter months a portion of its stored food supply.

Parasites get their food from living green plants or from animals. Another group of leafless plants, called "saprophytes," obtain their living from decayed or decaying vegetable matter on or in the ground. Parasites usually do harm to their hosts; saprophytes perform a real service as scavengers, cleaning up and disposing of decayed or decaying matter.

Most of these dependent plants do not take the trouble to flower. Mistletoe and robber dodder are among those which have small flowers, and it is a curious fact that the largest flower known in the world is the product of a parasite.

THE LARGEST FLOWER IN THE WORLD

This flower was entirely unknown until the nineteenth century, when Dr. Arnold, traveling with Sir Stamford Raffles in Sumatra, an island of the Dutch East Indies, came upon a monster flower, measuring fully a yard across, growing between the roots of trees. It was not a beautiful object, being of thick, fleshy texture and of a yellowish flesh color mottled with purple. The odor was most unpleasant. It was calculated to weigh about fifteen pounds, and its buds were as big as cabbages. The strangest thing about it was that there were no leaves and no proper stems, only long twisting roots which proved on examination to dig into the roots of neighboring trees and live upon their sap. Thus it was plainly a parasite, and an uncommonly successful one. The flower was named Arnold's Rafflesia, in honor of its two discoverers.

FUNGI — BACTERIA

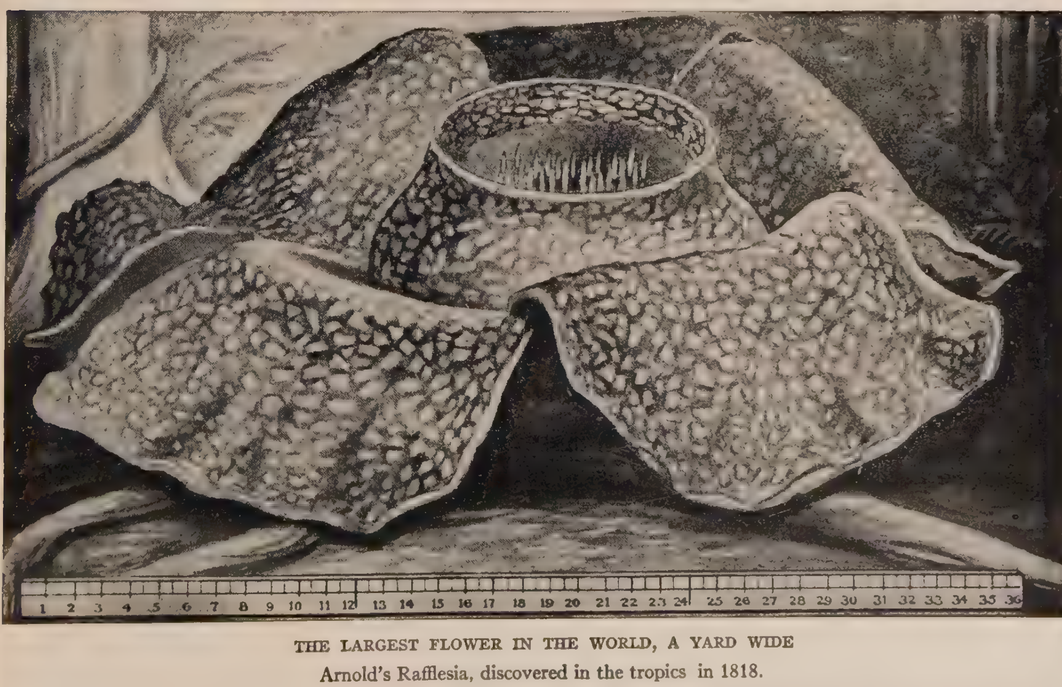
The flowering robber plants of which we have spoken are all outside of our ordinary experience. Familiar dependents of the plant world are fungi, mushrooms, lichens, and the ghostly white Indian pipe. They have no welcoming green leaf to turn to the sunlight, but must get their food as they can from neighbors and hosts. Still another group of dependents are the blights, molds, and mildew. Then there are bacteria, commonly known as "germs" or "microbes," tiniest of living vegetable organisms. They, too, cannot live independently. Yet they must have energy and material for their own existence. So they take it from their plant or animal hosts, or get it from dead matter. We look at bacteria from our human point of view, seeing some of them as harmful in their effect, as, for instance, the disease bacteria like tuberculosis, diphtheria, typhoid, or cholera, and some of them as harmless, and still others as positively beneficial, since they attack and dispose of decaying and therefore poisonous matter. From their own point of view (if they had one!) the bacteria which cause diseases in man or animals or plants are simply going about the very natural business of getting their living and reproducing after the manner of their kind. Fortunately the physician has learned to recognize certain of them as the active agents in diseases with which he has to deal, and he can therefore take measures to destroy them. They multiply so fast that he cannot always get ahead of them. If by his antitoxins and other means he can stop their action, the disease will disappear. To us in our story of life, the present interest in bacteria lies in the fact that all this preying upon others for their food comes about because they lack the miraculous power of the green plant to fend for itself.

MISTLETOE

Which takes food, but gives help to its host.

ROBBER DODDER

Which steals food and shelter, and often life itself, by its winding, clinging, sucking stems.



THE LARGEST FLOWER IN THE WORLD, A YARD WIDE

Arnold's Rafflesia, discovered in the tropics in 1818.

WHEN THE LEAF FACTORY SHUTS DOWN

The glory of life, as seen in autumn coloring — why red leaves and yellow — why the green disappears.

IN the temperate zones Nature shuts down its food factories in the early fall. As it withdraws its green-leaf trademark, there results a glory of autumn coloring which announces in unmistakable fashion that the year's work is done.

WHY LEAVES CHANGE COLOR AND FALL

So long as the parent tree is renewing its chlorophyll day by day, renewing it as fast as it is used up in the busy leaf factories, so long the green color is the conspicuous feature of the leaf. But there comes a time when the cells fail to get their necessary supplies. By some mysterious foreknowledge of the seasons, the tree begins to adapt itself to the coming winter. The leaves have done their part in the manufacture of food. Now the sap ceases to flow in such abundant measure. The tree begins to withdraw its valuable materials into the safe and protected parts of the tree, into the roots and trunk and branches, preparing to store them against the long winter instead of using them to make more chlorophyll and so gain more food. It even builds a wall of corky cells across the point where leafstalk and parent stem join. This wall, the quiet advance formation of which is one of the marvels of Nature, serves two purposes. It cuts off the supply of sap for the leaf, thus depriving it of its life-giving matter and causing its shrinkage and final dropping off, and it provides in advance a scar which is nearly healed by the time the leaf is torn away, so that in spite of the dropping off of hundreds upon hundreds of leaves, there is no leakage of sap, no danger of the tree bleeding to death.

HOW LEAVES TURN YELLOW AND RED

As the leaf becomes less active in the autumn, there comes a time when no more chlorophyll is made. The chlorophyll part of the leaf fades away, and with it goes naturally the greenness. Then according to the chemist who has analyzed the contents of the leaf cells, other substances have the chance to make their colors felt. One material which has been there all the time is, when it stands by itself, bright yellow in color. It has been covered by the greater brilliance of the green tissue except as it gave a yellowish tint to the green, producing the shade which we call leaf green. Now this yellow has its chance to show, and that it does show every admirer of autumn colors can testify. It gives to our landscapes the most familiar autumn tint, yellow.

There is another chemical which forms as the chlorophyll disappears and bright light is admitted to the cells of the leaf. It does not form in every kind of leaf, or in every leaf of a single tree, for it can be made only by the application of intense light, and it requires in its make-up other substances, especially sugar and probably tannin. When it does form it gives to the leaf a brilliant red coloring. This is the same red which we see earlier in the summer in certain plants and flowers. Beets have an abundance of it, as do many foliage plants and trees like beeches. Maples and oaks show in the early spring a lovely rose-red tint in their leaf-buds and young shoots, which fades away with their more rapid and vigorous growth. They are trees rich in sugar and tannin; so it is no wonder that this chemical appears in their leaves in great quantity, giving them in the autumn a gorgeous redness against the quieter yellow of their less endowed neighbors. Many leaves mingle the two colors, the red showing more plainly where the bright light of the sun penetrates, the yellow showing in the more shaded portions.

THE WANING OF LIFE

Absence of greenness is, then, the reason for autumn coloring, allowing for the recognition

AUTUMN FOLIAGE

of an ever-present but concealed yellow, and for the formation of other coloring matter, notably one giving forth a bright red shade. And this absence of greenness is the sign of the stoppage of work and the waning of life in the leaf. Sometimes it comes to a tree or to a single branch of a tree in the late summer when a lack of moisture, a cut in the trunk, a weakening of the roots, or any minor injury have checked the strong flow of life forces surging through it. Were a tree to try to hold its delicate leaves all winter, they would be sadly worn and torn, and in the attempt to care for them the tree would suffer a loss of heat and an output of effort which would be in danger of fatally impairing its life functions. The risk would be too great; the wastefulness, enormous in proportion to any possible gain. Nature does not willfully waste its forces or imperil its products. The delicate leaves have done their part; now they may go. Evergreen leaves have their leaves built especially for hard wear, small and needle-like or stocky and heavily rimmed. They can endure the winter without weakening the tree.

So as we witness each year the beautiful combination of leaf colors following the departure of the familiar green, we see that the green is not simply a trademark for a manufacturing process; it is that and much more, for that process is the sign of healthy life. Only in the resting time of the year, when in the rhythm of Nature life is for a period on the wane, does the greenness disappear. Green will be the sign of returning life in the spring.

HOW COAL CAME TO BE

The mystery of life — of sunlight buried for ages, imprisoned in the earth, dug from the earth to warm our homes and run our machinery.

IN the rhythm of Nature, as in the thoughts of God, a thousand years are as a day, and a day is as a thousand years. Its cycles may be as swift as the plant-animal cycle of our recent diagram, in which the sunlight of yesterday supplies the food of to-day and to-morrow; or, governed by the same law, they may be as agelong as the plant-coal cycle, in which the sunlight of forgotten ages and the plant life of prehistoric eras were the fashioning forces. For the plants and trees, the tangled swamps and the lofty vegetation of the time when the earth was in the making, took the carbon from the atmosphere by the same miracle-working process by which the green plant in the garden is taking it now. They held it imprisoned in stem and leaf, as the plant of to-day holds it, shutting it away from the oxygen with which it would naturally reunite. Then, in the upheavals which made and remade the earth, this swamp and forest vegetation of the so-called "carboniferous [carbon-making] period" went through a process of partial decay in water, and then was buried under tons upon tons of other matter. Shut away thus from the air which would have restored to the carbon its oxygen, it was held fast under tremendous pressure. The result we know; the carbon hardened into coal, and our great coal deposits were formed. When we burn coal, we are allowing the imprisoned carbon of forgotten ages to unite with the waiting oxygen in the air of to-day. We are completing a cycle which Nature began in those remote times when the earth was still in the making.

WHY SOFT COAL AND HARD?

Knowing how coal is formed, it is easy for us to understand why not all coal beds are alike. Speaking in general, the more solidly the carbon is packed together the harder the coal. If there still remain in it a considerable amount of carbon-hydrogen-oxygen compounds, the coal is less solid, or softer. Let us follow the stages of coal making as they are to be observed in Nature's great laboratory.

First comes cellulose, which is the solid framework of plants and of the wood of trees. When the water is partially evaporated from it, — when, as we say, it is "seasoned," — wood is an excellent quick-burning fuel. The carbon is very ready to unite with the oxygen of the air.

(Paper, by the way, made from wood pulp is very quick to burn. When we use paper to light our fires, we are still depending on the plant product with its stored carbon.)

In the Great Dismal Swamp of Virginia we are having exhibited before our twentieth-century eyes the first stages of the process by which our great coal deposits were formed. The framework of the plants and bushes and trees is being buried in water, and is crumbling to a black powder. If it should be buried for ages under many tons of earth, the pressure with its resultant heat would compact the carbon particles into solid rock, coal.

Peat is another stage in the carbon fuel cycle. Peat is a carbon compound caught in the process of changing to a carbon powder; this may have the water dried out of it and then be used as a fuel. Lignite, often called "brown coal" or "wood coal," is the next stage, having less cellulose and more carbon than has peat.

Bituminous or soft coal comes next. If the black powder of the Great Dismal Swamp were buried for ages, there might still remain a considerable percentage of oxygen and hydrogen in the form of hydrocarbons, which would make what we call "soft coal," for it would be more easily converted into vapor. But let the black carbon powder of our Dismal Swamp be subjected to very great heat and much of the hydrogen and oxygen would be forced out of the coal. The result would be anthracite or hard coal. It has very little volatile matter and a large carbon content. In the United States anthracite is expected to have anywhere from 85 to 95 per cent of carbon content. Anthracite is the last step in our coal cycle. Yet it is interesting to follow carbon into two other stages, formed under slightly different conditions. One is graphite or black lead, which makes the leads of lead pencils. The other is the diamond, which is pure carbon crystallized. If, therefore, we were to carry the carbon cycle from its plant stage through to the stage where pure carbon comes out, and then were to restore it to its original carbon dioxide compound (in the air, as the plant received it), we should have to indulge in the reckless practice of burning diamonds.

IMPRISONED SUNSHINE

Look at your glowing fire and think of it as releasing carbon which has been imprisoned for long ages. Watch the diamond on your finger as it reflects from its prisms the sunlight colors of the twentieth century, and remember that it is the product of the sunlight energy of unknown centuries, shining on a vegetation which no human eye ever saw. Carbon of to-day imprisoned by green plants, and we and all the animal world gain our power of life and motion by its energy! Carbon of long ago imprisoned by green plants, and the twentieth-century miner digs deep for the fuel by which our homes are warmed and our industries maintained!

LIFE AND ENERGY

The scheme of life — how it captures energy from sunlight, stores it in food, and releases it in breathing.

THE only way to get even a slight impression of "The Wonder of Life" is to approach it from many sides and angles. So a mountaineer gains a sense of the majesty of a mountain by viewing it from each of the neighboring valleys and climbing toward its peak along trails leading from the east, the west, the north, and the south.

It is our habit to think of life first as it shows itself in living forms, in birds and beasts and fishes, in trees and flowers. By this procession of its visible and triumphant creations is life daily exhibited to every one of us. Close upon the heels of the natural interest thus aroused in living things comes curiosity as to how these wonders are accomplished. From seeing *what* life does we come to the question of *how* life does it. With this question in our minds we do well to follow along a little way on the trail of life in its relation to energy. To do this is to approach the problems of life from the purely mechanical standpoint. Machinery is such a commonplace of our modern life that it is often helpful to apply its tests to the natural world. Viewed thus the whole machinery of living creation shows a marvelous unity of plan coupled with an amazing variety of form and method.

LIFE HAS A THREEFOLD AIM

As a machine maker and a machine user — and what from the mechanical point of view are plants and animals but machines? — life's prime requisite is energy. This energy the sun is constantly supplying. To divert this flood of energy into the stream of its own activities is life's business. Practically, the problem arising in connection with this supply of energy resolves itself into three parts: it must be caught, it must be held, it must be used. Life's aim, on the mechanical side, is therefore threefold, — the capture, the storage, and the release of energy. So simply and clearly can the great problem of life be reduced to a least common denominator.

THE CAPTURE OF ENERGY — FROM SUNLIGHT

With life's method of capturing energy from the sunlight we are already made familiar. By means of the chlorophyll in the green leaf it is caught and utilized to pull apart the elements of the air. "Chlorophyll," says John Burroughs, "is the miracle worker of the vegetable world, it makes the solar power available for life. It is in direct and original relation to the sun."

Plants, "green things growing," are the machines set up for the capture of sunlight energy.

HOW PLANTS ARE BUILT TO CATCH SUNLIGHT

To say that plants or animals are shaped and fashioned in this way or that for some special purpose is often unsafe, for we may be leaving out of account equally important influences which are making for the same or different results. But as the capture of sunlight is one of the chief functions of the plant, we have the right to think that many of its special features are closely connected with this function.

Since chlorophyll is the agent for the capture, how natural that this green tissue should be spread out thin over a big surface! You remember that the area of the green leaves of a maple tree was estimated at half an acre if they were spread out side by side. Light does not penetrate far into a body, but touches the surface and is caught or glances off. What better arrangement could be found than the flat, thin leaf? Consider how economical of space is its grouping on plant or tree! If the leafage of a single tree would cover half an acre spread out flat on the earth's surface, the amount of sunlight-capturing green tissue would be too

limited to maintain life had not some scheme for close packing without overlapping been evolved. Try your utmost and you cannot devise a better scheme than that of the branching plant or tree for hanging out green leaf-matter so that, in the daily progress of the sun across the heavens, it

BREATHING TUBE OF A MOSQUITO LARVA

will catch the right amount of sunlight, direct and reflected. The architect who plans an assembly hall so that from each seat the center of the platform may be in full view has a simple task compared with the planning of a mighty tree so that each leaf may have a good average exposure to the light without shading its neighbors. Study the forms of trees and plants, the way leaves are hung on stems and branches, and see if you do not agree that for the capture of sunlight energy by surface contact, Nature has here perfected a remarkably efficient machine.

THE STORAGE OF ENERGY — IN FOOD

If electricity could be perpetually drawn from lightning as it was through Franklin's kite and as promptly set to its appointed task, we should have no need of power houses or batteries or trolley wires or electric heaters. To be useful and usable in a complicated modern world, electricity must be stored and held in reserve for use when called for. Similarly, to run the complex organisms of life, energy must be not only caught as sunlight, but held, carried from the place where it is taken into the place where it is to be released for work, and often stored there for future use.

Food is the storage battery for such holding and transfer of energy. This we have seen in our story of the "cycle of life," where the plant built up the imprisoned carbon into various food combinations, familiar to us as starches and sugars, the animal ate that plant food, used part of it and stored part of it, and man completed the process by eating both plant and animal food. The story of food in its capacity of storing energy deserves and shall have a separate chapter, for it bears directly on our daily menu. Here we are thinking of it only as a mechanical device for holding energy. Could anything be more economical and efficient than this curious chemical scheme, of pulling apart elements that have a strong tendency to stay together, letting them be carried through a succession of processes, in the course of each one of which more energy is stored or, if it is needed to work plant or animal machinery, necessary energy may be set free, until at the proper moment in the proper spot takes place the final act of the program, the release of energy?

Think of the innumerable ways in which the bodies of animals are adapted to the getting and using of food! The beaks and bills and pouches, the claws and snouts and fishing poles, the mouths and teeth and tusks, the stomachs and crops and gizzards — all adapted for food getting! Think how the camel stores food in the hump on his back, how the bee colonies make and store honey, and the squirrel lays aside his store of nuts! Truly the ways in which life has fitted its living creation to seek and to store food are almost without number. Yet each and every one has for one of its purposes the storage of energy, ready for its ultimate release.

THE RELEASE OF ENERGY — BY BREATHING

Food has been likened to a storage battery. It is by another figure "a kind of explosive,

which needs only the spark to discharge the energy it stores." And here we come to another big subject, for the method of discharge is by breathing. The breathing pores of the plant, the breathing tubes and other similar organs in insects, the gills of fishes, the lungs of man and of the other higher animals, are all parts of the energy machines. The fish in the depths of the sea must have some apparatus by which he can let in oxygen to meet the carbon of his food.

The whale must come up to the surface to breathe in air to discharge his food batteries. Not a creature that lives but must eat and breathe —but must take in energy in food and have it released within his cells to keep the machinery of his body going. The release comes when carbon and oxygen meet. From the slow-burning fires in the cells come heat and energy.

The more we are interested to follow out in this volume the way that plants and animals are built, their curious forms, and more curious habits, their means of getting about from place to place, and all the detail of their daily life, the more we shall realize the infinite variety in mechanical device which life has perfected and is making use of for the storage, the transfer, and the release of energy.

IN OTHER WORDS

The following passage from John Ruskin's "Modern Painters," Volume V, is part of a most interesting study of "The Leaf," to which the reader will do well to refer. The paragraphs here quoted carry out poetically the thought suggested in the text of the way in which the leaves of a tree are arranged for the mutual benefit of all.

"For the leaves . . . are the feeders of the plant. Their own orderly habits of succession must not interfere with their main business of finding food. Where the sun and air are, the leaf must go, whether it be out of order or not. So, therefore, in any group, the first consideration with the young leaves is much like that of young bees, how to keep out of each other's way, that every one may at once leave its neighbors as much free-air pasture as possible, and obtain a relative freedom for itself. This would be a quite simple matter . . . if each branch, with open air all round it, had nothing to think of but reconcilement of interests among its own leaves. But every branch has others to meet or to cross, sharing with them, in various advantage, what shade, or sun, or rain is to be had. Hence each single leaf-cluster presents the general aspect of a little family, entirely at unity among themselves, but obliged to get their living by various shifts, concessions, and infringements of the family rules, in order not to invade the privileges of other people in their neighborhood.

"And in the arrangement of these concessions there is an exquisite sensibility among the leaves. They do not grow each to his own liking, till they run against one another, and then turn back sulkily; but by a watchful instinct, far apart, they anticipate their companions' courses, as ships at sea, and in every new unfolding of their edged tissue, guide themselves by the sense of each other's remote presence, and by a watchful penetration of leafy purpose in the far future. So that every shadow which one casts on the next, and every glint of sun which each reflects to the next, and every touch which in toss of storm each receives from the next, aid or arrest the development of their advancing form, and direct, as will be safest and best, the curve of every fold and the current of every vein. . . .

" . . . Upon it [the leaf] . . . the great merciless influences of the universe, and the oppressive powers of minor things immediately near it, act continually. Heat and cold, gravity and the other attractions, windy pressure, or local and unhealthy restraint, must, in certain inevitable degrees, affect the whole of its life. But it is *life* which they affect,— a life of progress and will,— not a merely passive accumulation of substance."

Photo by S. Leonard Bastin

HOLES IN LEAVES

Every leaf must have sunlight if it is to do its work. This tropical plant has holes in its leaves to let light through to the foliage beneath.

PICKING BREAD OFF A TREE

Copyright, Underwood & Underwood

AN EASY WAY TO LIVE

From the beautiful breadfruit tree of the tropics a man may pick a fruit from four to seven inches in diameter which has within its thick rind a soft, spongy interior almost similar in consistency to newly baked white bread, and sweet and pleasant to the taste.

Photos by E. R. Sanborn, New York Zoological Society

CASSOWARIES — FLIGHTLESS BIRDS

LIFE IN THREE ZONES

Life in the air, life in the water, life on the ground—how some families are successful in all three zones — of the requirements for life in each zone.

NOTHING about life is more amazing than its persistence under varied conditions. It has a tendency, as Sir Oliver Lodge remarks, to "catch hold wherever it can." The fact that water proved a satisfactory place of abode for a whole kingdom of creatures was no reason why land should not be tried out as fully as a dwelling place. That the surface of the earth could rear and support an army of walking, creeping, or rooted animals and plants did not mean that life would stop there. With an ocean of air above the earth, life promptly took advantage of its possibilities for birds and insects. The Creation story leaves no zone unpeopled with living things.

To each group of creatures its own way of living seems the normal and therefore the only reasonable way to live. Since it suits our style of make-up to walk about on the ground with our heads in the air, it seems to us that to have solid earth beneath one's feet and be bathed in an ocean of air is the proper setting for life. Yet fish would find such conditions intolerable. "Here is a planet more than two-thirds covered with the natural medium for life, water," they might say, "and yet these creatures try to pass an existence out of water." Water creatures could poll a tremendous vote when it came to a contest as to which kind of surroundings suited the most living things. Birds might well consider our style of life limited and rather stupid. "It is all very well to use the surface of the earth as a home and a feeding ground," they might say, "but these human beings act as if they were tied to it. They do not seem to know how to use air." Life is evidently not partial to one limited type of surroundings. It flourishes in all. Yet the conditions of life on earth, in air, and under water are quite different. Much of "The Wonder of Life" lies in the ways in which creatures are adapted to the conditions of their environment.

THE SPIDER FAMILY LIVE IN ALL THREE ZONES

Many creatures live in two zones; the spider family tries out all three. As an acrobat or conjurer throws a rope into the air and climbs it, so the young spiders toss out into the air long threads and go a-flying. It is not real flight, like that of the birds, but is more like the ballooning or parachuting practiced by seeds. "Although spiders like men possess only legs as organs of locomotion," writes Comstock, "like

men they are able to travel through the air by artificial means. Long before the invention of balloons or aëroplanes, spiders had solved the problem of aërial navigation. . . . It is usually, but not invariably, very young spiders that exhibit the aëronautic habit; and exhibitions of it are most often observed in warm and comparatively still autumn days. . . . At this time great numbers of young spiders, of very different species, climb each to the top of some object. This may be a fence post, the top of a twig, the upper part of some herb, or merely the summit of a clod of earth. Here the spider lifts its abdomen and spins out a thread, which if there is a mild current of air is carried away by it. . . . This spinning process is continued until the friction of the air upon the silk is sufficient to buoy up the spider. It then lets go its hold with its feet and is carried off by the wind. That these ballooning spiders are carried long distances in this way is shown by the fact that they have been met by ships at sea hundreds of miles from land."* It is a pretty picture which any one of us may be so fortunate as to see on an autumn morning, these little spiders sailing off on their threads of silk. "The caprice of the breeze," says Mitchell, "determines the course and distance of the flight, but just as the spider can haul in the thread which binds it to a spot from which it has dropped, so when it is floating it can roll up its sail, piece by piece, until it descends to the ground." So the spiders of many species are not content to settle down to an earth life without an adventure in the air.

The spider is naturally an air-breathing earth dweller, spinning webs on the grass or at any level to which its swift legs may carry it. The trapdoor spider takes a greater advantage of the earth on which he finds himself, tunneling into it for safety, spinning a silken wall for the lining of his home, and then, with an amazing burst of architectural skill, closing his home behind him with a hinged lid, so cunningly fashioned as to be almost invisible when closed. The solid earth is to him not only a home but a fortress.

The European water spider performs the most wonderful feat of all. It is one of that adventurous group of creatures which although they are built for air breathing and so would seem to be required to spend their lives on the earth's surface, yet prefer to live under water. They are not fitted for water life, as is the fish, with gills by which to extract oxygen from the air which has been caught in water. They must have air of the above-ground or the above-water kind. So they get it and carry it under water with them, just as the human diver takes down his supply with him. Thousands of years before man learned to descend into the water with his diving bell full of air, the water spider had made for itself at the point where it wished to live a thimble-shaped case of silk, fastened by anchor cables to the water plants about it, with the opening turned downward. Three of them can be seen in the picture. A spider is in the act of slipping into the lowest one at the right, carrying, entangled in the hairs on his back, a silvery bubble of air. These hairs are long and hooked. Above water the air does not show. While he swims down you can see it like a bubble on his back. As he slips under the opening of his diving-bell home, he releases the bubble which by reason of its lightness rises to the top of the bell, driving down and out the water which it displaces. Bubble by bubble the spider fills the dwelling until he has a water-tight air chamber. This air-filled bell serves as a home, a nest for the young, and a place of retreat. The water spider works hard for his air. He is kept busy replenishing the supply as it becomes exhausted. But by his clever device he has achieved for the spider family the rare distinction of living successfully in all three of the possible zones, — earth, air, and water.

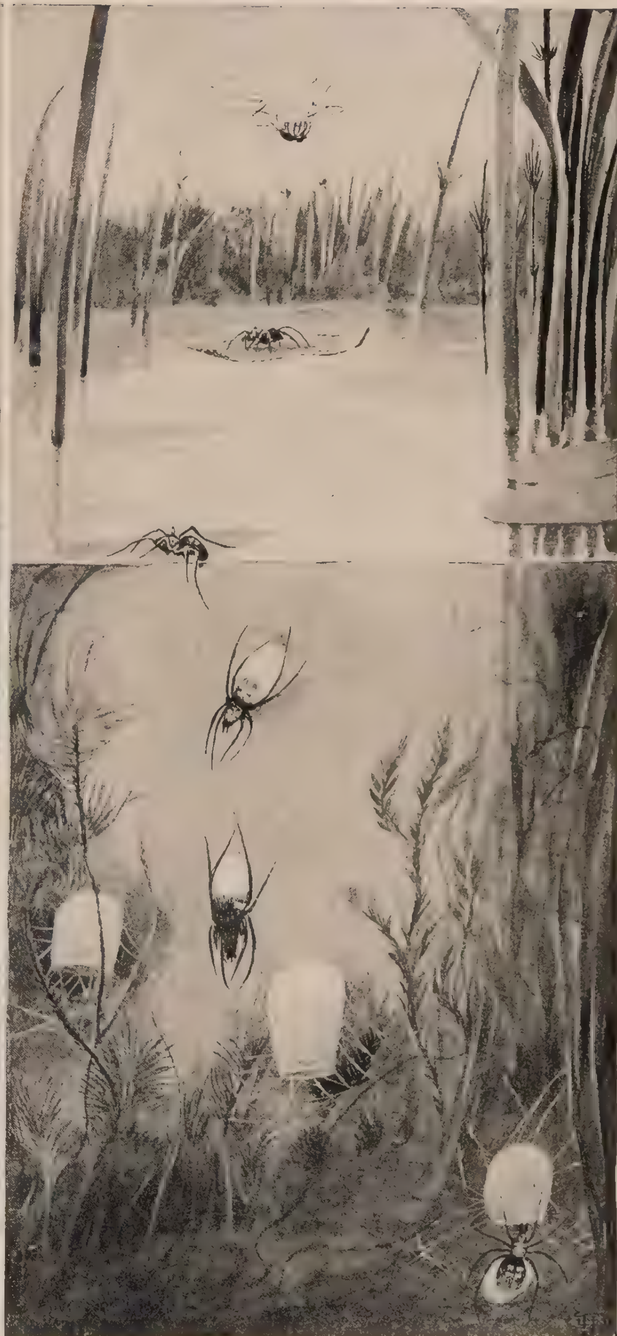
IF ONE WOULD LIVE ON EARTH

We have followed the spider family into each of the zones and seen how different members adapted themselves to the requirements of each. Now it will be interesting to take this idea of "life by layers" and note that many of the characteristics of each group of animals are explained by the zone in which it lives. Life in the two upper zones, the earth and the air, has an obvious requirement. One must be able to breathe dry air. Somehow or other, through the skin of the lower animals or the air tubes of the insect, or the lungs of the higher animals, dry

* See also Volume III, pp. 20 and 329.

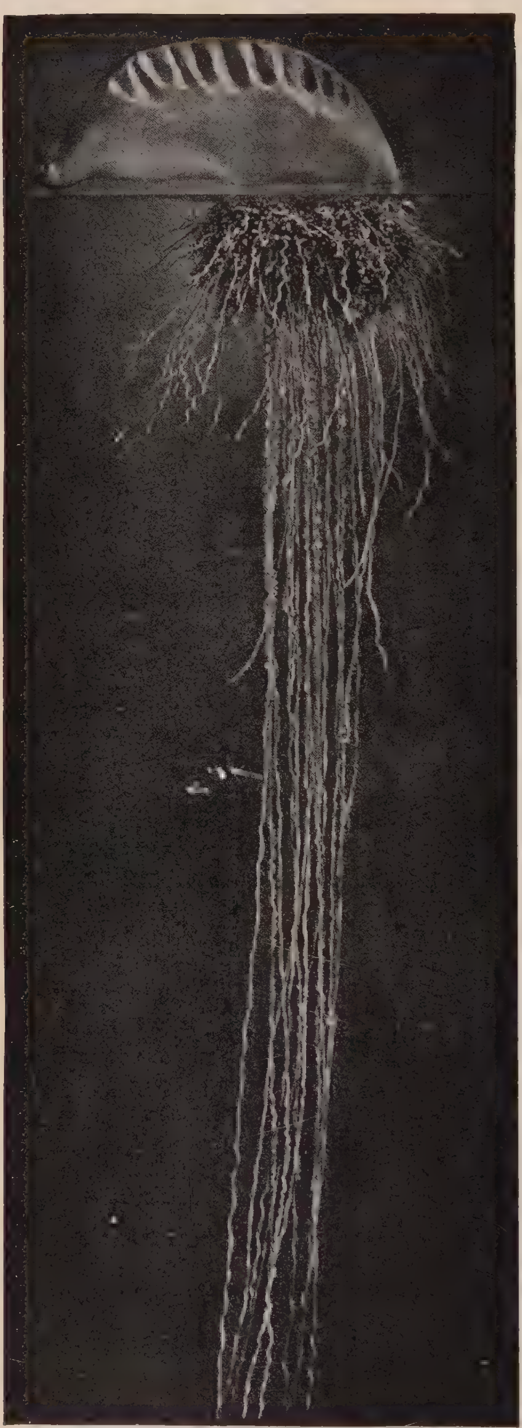
THE DIVING BELL A SPIDER INVENTION

BALLOONING AND TRAPDOOR SPIDERS



WATER SPIDERS WITH THEIR DIVING BELLS

Like human beings spiders are not content to stay on solid earth. Young spiders go ballooning, tossing out long threads to balance themselves. The trapdoor spider digs his home, lines it with silk, and fits it with a door with a hinge. The water spider wants to live under water but must have air to breathe. So centuries ago he invented the diving bell, building a thimble-shaped home and carrying down air bubbles to fill it. When his supply of air is exhausted he goes up for more.



American Museum of Natural History

PORTUGUESE MAN-OF-WAR — A FLOATING COLONY

The richly tinted bladder is inflated as a sail; the hanging streamers have a powerful sting.

air must be taken in, so that its oxygen may act as the spark to explode stored food into energy.

The atmosphere at most points on the earth's surface is very changeable. It is not uniformly wet or dry, hot or cold. It varies daily with the presence or absence of sunlight; it varies with the changes in season, winter and summer, rain or drought. No life spent on the earth's surface can ever be as free from such changes as, for instance, life in the cold, dark depths of the sea might be. The animal who would live a thoroughly terrestrial life must, as Professor Cuénot has pointed out, be able to resist a considerable range of variation in temperature and humidity. To the need for meeting such a variation science charges many animal assets, — hair and feathers and fur to keep the creature warm and dry, and temperature-regulating devices like the blood-pumping heart to keep the temperature adjusted to conditions. In some kinds of worlds none of these things might be necessary; in our life zones they are.

Life on the earth is rather dangerous. It requires a considerable amount of protection of one kind and another. So the young of earth animals must be carefully protected by their own coverings, as are the embryo birds in the shells, and later by their parents, and must grow fast to a size and maturity where they can look out for themselves. This is something we should not so readily notice, but we can see at once that it may be true.

Life on the earth for a creature that must go in search of its food requires special organs of locomotion. Snakes get about without feet or legs, but most earth animals depend on feet and legs for locomotion.

From this single thought of life on the earth zone, we find ourselves led into stories of how we breathe, of how we move from place to place, of warm-blooded and cold-blooded animals, of climate and the kinds of covering for each climate, of how animals keep dry, and of how they care for their young. One could write a whole book of earth-zone stories. But then there are the air creatures and the water creatures.

TO LIVE IN THE AIR

To live in the air, or rather to make use of the air as a free medium for movement, one must

be built on certain fixed lines. Not only must there be wings for flight; the body must be so shaped as not to offer undue resistance to the air which it cleaves. The engine within the body must be light but extremely powerful. Food cannot be stored long; it would be too heavy a weight. It must be put through the body rapidly. These conditions which are necessary for a successful flying machine mean the sacrifice of certain other possibilities. Birds cannot store enough food to go into a winter sleep as many animals do. They are not built to weather cold and protracted storms. So they make up for this by depending on their power of flight to take them to warm climates. Migration is their answer to the problem of a changing season. It is not a universal answer. Many birds spend northern winters, but they, too, have their devices for self-protection. As man is beginning to adventure in the air zone, we shall be especially interested to follow out in later stories its requirements.

FOR LIFE IN THE WATER ZONE

All life requires oxygen from the air. Even in the water this is necessary. So the water creature must be able to get this oxygen. The fish has gills by which he can filter into his blood the oxygen from the air caught in water. A fish would suffocate in pure water with no air in it. The fish does not need feet or legs by which to get about, but his body must be as carefully shaped to slip through water as the bird's to slip through air. There must be organs by which to propel and steer the body—the fins. There must be mechanisms for keeping him down in the water, else he might float to the surface because of the buoyancy of water, as the human swimmer does, and for enabling him to go up and down in his water world as well as forward, sidewise, or backward. In a coming chapter Professor Longley tells how he went down himself and lived under water with the fishes, while from others we learn of those sea depths where grotesque soft-bodied fishes spend their lives under a pressure of tons of water.

This article merely introduces us to the idea of the three zones and the interesting adventure of life in each. Before we consider life in any single zone, we shall have the stories of some adventurous creatures that have moved out from their own zone into another and live, as it were, "on the borderland," between zones.

Courtesy of American Museum of Natural History

A LIVING LUNGFISH — FROM AFRICA

Most fishes get oxygen from air caught in the water which passes over their gills. This fish has lungs as well as gills, so that it can breathe in the open air and need not always stay in water. In the long dry season it buries itself in mud and goes for months without food or water, somewhat as a bear hibernates. With the return of the wet season it resumes its normal water life.

CRABS THAT CLIMB TREES AND TAKE JOURNEYS

IF you lived in a hill country, many miles back from the seashore, you would not expect to meet a crab in your garden. Crabs are creatures which we always associate, and rightly, with the seashore and a water life. But there are two species of land crabs of the tropical islands of the Indian and Pacific oceans which have adapted themselves to a land life. The upper gills are changed so that they can breathe dry air; the lower part of the gill chambers are still adapted to water life, for it is a custom of these crabs to make an annual pilgrimage back to the water home of their birth to lay eggs and so start the young crabs in the old surroundings, from which they in their turn will journey when they are sufficiently grown. It is during one of these pilgrimages that you would find not one but many in your garden if you lived on one of their routes to the sea. "At the approach of the spawning season," writes Duncan, "vast armies of these crabs set out from the hills and march across country, regardless of all obstacles, in a direct line to the seashore. Arrived at their destination, the crabs proceed to deposit their eggs in the sand below high-water mark, and this safely accomplished they start on their toilsome march homeward to their upland retreat. On their way down to the sea they are fat and in fine condition, and large numbers are caught for food; but on their return they are poor and exhausted, and useless for the table." A column of these migrating crabs has been estimated to be forty feet wide and a mile long.

Mr. Duncan is describing above what he calls the "countryman crab" (*Gecarcinus ruricola*). Another species is the robber crab, or coconut crab (*Birgus latro*), shown in our picture. That this crab actually does climb trees can be proved by photographs. He is a big creature, sometimes attaining a weight of twenty pounds. "The appearance of these giant creatures," says Zimmerman, writing in *American Forestry*, "crawling through the woods makes one feel decidedly creepy. The animals are easily frightened, and scuttle off backward at the slightest alarm. They live not only on coconuts, but feed on fruits of various kinds, especially that of the sago palm. . . . This crab lives in a hole in the earth under trees, lining its burrow with the fibers of the coconut husks. It has an almost lunglike modification of the gill cavity for breathing air directly, yet visits the sea annually in droves to spawn. In climbing, this crab scarcely uses its large claws, but clings to the tree with the sharp points of its walking legs. It can also climb almost vertical rock faces." It climbs the coconut trees to get the nuts, which it pierces and opens with amazing skill and swiftness.

FISH OUT OF WATER

NO words call up to our minds a more vivid picture of discomfort than the familiar phrase that under some trying circumstances a person felt "like a fish out of water." The ordinary fish has no adaptations for life outside his watery world. Yet among the wonders of Nature are species of fish which cannot only live out of water but also skip across the drying mud of marsh lands, and can even climb up the side of a tree trunk and bask comfortably in the sunlight. The explorers or early travelers who brought home the first accounts of these curious members of the fish family were thought to be telling fairy stories, but cool, sober, observant science has proved them right.

The reason why the ordinary fish cannot stay out of water is that he cannot breathe dry air; he must get his oxygen through water by means

WHERE FISH TAKE WALKS ON LAND

It sounds like Topsy-Turvy World, but if you will read the stories you will find it is all true. See the crab at the right carrying in his strong claws the coconut which he will crack and eat, and the fish with bulging eyes lying comfortably on a tree trunk.

of gills. All the fish which do stay out of water have some special arrangement for breathing. Either the gills can by some device retain enough water to keep them moist for some hours and thus enable the fish to breathe, or there is some sort of lung or air chamber which marks the fish as one of the creatures of "borderland" life between zones.

GOBIES PLAY ON SHORE LIKE LIVELY KITTENS

A. Hyatt Verrill gives an interesting account of the goby, shown on the tree trunk in our picture. "Gobies live mainly in warm countries, where they often crawl out of water in large numbers and skip and play on shore like lively kittens. In the countries where these wonderful fish are found the shores in many places are covered with low mangrove trees, and up these the gobies climb in search of food. You can imagine what an odd sight it must be to see a lot of goggle-eyed fish walking and hopping about on land and climbing up trees in search of insects."

These fish have developed out of their fore fins what look like arms, with hands with webbed fingers, which help them to get over the ground, and out of their hind fins a kind of sucker or sucking disk by means of which they can cling closely to the bark of a tree. They progress by jumps or leaps which have gained them the name of "mudskippers." A goby will go "skipping along over the wet sands and mud, even skimming with great speed over the surface of the water," says one writer. "It chases its insect prey among rocks, leaves, and weeds, and out of the water is as agile as a lizard." The eyes are raised on stalks so that the creature can look in all directions without turning the head. Gobies have been timed to stay from three to six hours out of water.

CLIMBING PERCH

The climbing perch of the fresh waters of India, Burma, Ceylon, and the Malay countries is almost more wonderful than the goby. "It not only climbs trees," says Mr. Verrill, "but marches overland for long distances, traveling across high hills and wide, dry plains from one river or lake to another. This fish travels by means of stiff spines on the gill covers and can live for a long time out of water, as within the head is a series of chambers where water is stored for the fish to use in breathing when on land." This climbing fish, known as *anabas* (from the preposition *ana*, "up," and the verb *ba*, "go"), was first reported by Lieutenant Daldorf of the Danish East India Company, who stated that he himself had taken one of these fishes in a slit in the bark of a palm. It was a long time, however, before his word was credited and it was admitted that a fish could not only stay out of water but climb five, six, and seven feet up a tree.

There are catfish in the Amazon district which will travel during the dry season on a cross-country run from one pond that is drying up to another with more water. "These journeys are of such a length that the fish spends whole nights on the way, and the bands of scaly travelers are sometimes so large that the Indians who happen to meet them fill many baskets of the prey thus placed in their hands." To meet a fish out walking and pick it up is certainly a unique method of fishing. Yet our own first-hand knowledge of eels and minnows of United States shores and waters which can travel in moist grass or go from pool to pool will make us ready to stretch our minds to accept these greater marvels of the tropics.

A STORY OF CLIMBING CATFISH

An American engineer, Mr. R. D. O. Johnson, has given an entertaining account of his experiences with climbing catfish high in the upper Andes in the Republic of Colombia. Mr. Johnson and his brother were installing a hydroelectric plant for a gold-mining company. In the course of their operations they turned aside the water of a stream which was flowing down the steep sides of a cañon. The bed of this stream was, on the average, thirty-eight degrees from horizontal—that is, nearly halfway to the perpendicular (which would have an angle of ninety degrees) — and the rocks were worn smooth by the rush of water that tumbled headlong over them. Not a quiet, pleasant home for a fish, one would say! As the potholes made at the foot of the waterfalls by the impact of the water not infrequently contained gold, Mr. Johnson's brother began to dig out an old

gravel-filled one which he found in the bed of the stream after the water had been turned aside. We will let Mr. Johnson tell the story in his own graphic way.

"He had been at this task for only a few minutes when he called out to me: 'Say, here 's a fish.'

"I replied saying something about his 'seeing things,' and proceeded to expatiate upon the impossibility of his finding a fish in such a place, and upon the utter inability of any fish even among the best swimmers, to surmount the difficulties of such a stream.

"I pointed out the absurdity of imagining a fish swimming with nine tenths of its body out of water, as it would have to be, up that part of the stream where the water passed in a thin sheet over the smooth rocks. 'He 'd have to be an aviator,' I said. So I pooh-poohed the idea recklessly.

"Harry listened with suspicious patience to my lengthy dissertation . . . ; then he blurted out: 'Well, are you all through? Here 's the fish!'

"He held in his hand a living fish, and a catfish at that, resembling the catfish or horned pout of the North. I took it and looked it over. There it was, a real live fish, nearly a half foot long. . . . Harry had his laugh and returned to his digging. I was completely puzzled — but I had pressing work to do. I carefully placed the fish in a small pothole at one side. This hole was about four inches in diameter and twelve inches in depth and held perhaps two or three inches of water. Catfish are hardy, so I figured that there was enough water to last this little fellow until I could give him more attention.

"After I had finished my work at the weir, I returned to the little pothole to give that amazing fish a closer scrutiny.

"He was not to be found, so I called out, 'What did you do with the fish, Harry?'

"Harry asserted that he had not taken the fish. . . . That certainly was a mystery. I did not think it possible for a five-inch catfish to jump out of a four-inch pothole twelve inches deep. . . . Before we returned to the camp that afternoon, Harry had caught two more 'cats' in another pothole. These we carried down to the camp in our dinner pail. We arrived at the camp just as the late afternoon meal was being served. I hastily poured the water and the fishes from the dinner pail into a three-gallon galvanized bucket and set it in an inconspicuous place outside the kitchen. After dinner I sought the bucket to get a better look at the fishes which had destroyed a good theory. They were not in the bucket. I inquired of several who might possibly have freed the fishes but no one knew anything about them. . . .

"The next day I made a special trip up the power stream and managed to secure two more of these fishes. I brought them down to camp and placed them in the same pail that had held the others and sat down to watch their maneuvers.

"For a time they were content to swim about, butting their blunt noses against the sides of the vessel. Then, to my amazement, one of them thrust its 'nose' out of the water and began creeping up the side of the pail. I watched it hitch itself up by short longitudinal movements until it had reached the top edge and fell outside of the bucket."

Mr. Johnson studied these fish until he saw how, by the sucker mouth and another sucking structure on the under side where fins were attached, they were able to create a suction pressure and by means of the alternate action of the two suckers to crawl, inchworm-like, on a smooth, vertical surface. Other fish of the mountain streams of the Himalayas cling and climb by means of similar apparatus, as do some tadpoles of these mountain torrents.

"Shortly after this," continues Mr. Johnson, "the mining company undertook the cleaning out of a large pothole which was eight feet in diameter and twenty-two feet in depth. Before the bottom had been reached, the water that remained in the pothole was found to be full of these climbing catfishes. . . . I surmised that as soon as the work stopped for the lunch hour these fish would essay the long climb to the top. I was not mistaken and my watching was rewarded by seeing four climb up a distance of eighteen feet to the pool of water above. They followed a thin film of water that trickled down the rock. This water kept their gills wet and sustained them on a climb that must have been arduous. It required half an hour to make the ascent.

"To my own satisfaction I had answered the question of how it was done; there remained the question of why. The fish was evidently a case of extreme modification and adaptation to a peculiar environment. Some catfish do not climb, why should these? An analysis of the environment brought the answer.

"I found that the Andean torrents were the habitat of myriads of these curious creatures. . . . The individuals I had examined were living in a torrential stream almost daily subjected to the sudden fury of sweeping floods. The violence of these floods is unimaginable to one who has not witnessed them. It seems that nothing unanchored in the stream bed can withstand their wild energy. . . . To remain at home in time of flood, these denizens of the wild waters anchor themselves by means of their sucker mouths. . . . These catfishes are to be found in all parts of the streams. . . . Travel they must, and by using the climbing mechanism I had seen operate — the alternate action of mouth and ventral suction plate. That they are able to surmount even great falls is evident from their presence in the Santa Rita Creek, for this stream falls into the Santo Domingo River over a precipice more than two hundred feet in height." *

* From *Annals*, New York Academy of Sciences, Vol. XXII, pp. 327–333, December 20, 1912.

THE FAMILIAR WONDER OF A FROG'S LIFE

An adventure in life — how a frog starts as a water creature, becomes a land dweller, and returns to the water — how he climbs his whole family tree in three months — of a frog that grows smaller as he gets older — of baby frogs in pockets.

A FROG takes at full speed a leap from life in one zone to life in another, which life in general has been many thousands of years in accomplishing. It is as if science had been trying to make us read chapter after chapter of a long, continued story, covering ages of time, telling how life began in the water and finally climbed up on land, and Little Frog came in while the tale was dragging out to long and complicated lengths, and said, "Here! I 'll show you how it was done. It is as easy as can be. You watch me for a few weeks, and I will run through the changes for you." So Little Frog takes the stage, and does the trick before our eyes. For a quick-change performer he holds a high record.

THE FIRST STAGE

Little Frog begins in an egg, one of a thousand or two dark dots in a lump of jelly. Right next to the tiny black egg is a layer of foodstuff, something like the yolk of a hen's egg; outside it the globe of jelly. This jelly is not itself alive. It is somewhat like the white in a hen's egg in the way it protects and serves the eggs. But there is no shell around this jelly. When Little Frog hatches out of the egg, he has no shell-enclosed world in which to grow until he seems more fitted to fight the battle of life. He is simply out in a great world of water, a funny half-finished little creature, all wrapped up in a membrane of skin that covers even his eyes. He has no mouth, no limbs; he is blind. All he has to give him a start are a sucking pad under his head by which he can hang on tightly to a water weed, and the beginnings of little gills like those of fishes through which he can breathe. He must be able to breathe, you know, for every creature must breathe. Since he is a water creature, he must breathe through water, and gills are Nature's patented water breathers. Look at him carefully every instant, for he has the magic of life in him, and before you know it, he will be changed into something else. In this stage while he hangs motionless waiting for a mouth to grow, he lives on what remains of the "yolk" which surrounded him as an egg. This is what the tiny chick in the shell does, what the embryo plant in the seed does. Nature almost always packs a small food supply about the helpless newborn life.

LITTLE FROG BECOMES A TADPOLE

Next Little Frog becomes a vegetarian. A mouth opens up, right where he is clinging to the water weed, and he begins to enjoy a weed diet. Eating agrees with him, and his mouth develops with horny jaws and points all over the lips which serve as teeth. Inside parts develop, too, so that he is a fully equipped little creature ready to eat anything that comes his way, animal or vegetable. But while this is happening, he is growing fast into the little tadpole which every one of us has seen or can see darting about in the water of some near-by stream, or in an aquarium of our own, if we have dipped up from the water in early spring a mass of frog's eggs. By much feeding his body has become large and round. But most important of all he develops a tail. Perhaps a tail does not seem to you a very useful or desirable thing to have. Watch Little Frog. With that tail he can swim. It is his oar, his propeller, by the waving of which from side to side he can dart up and down the world, a watery world still.

WATCH HIS TAIL

Thus far it has been a water life, with no hint of anything else ahead. But that tail has a secret. Hidden in it are the beginnings of two legs, hind legs, which soon show like buds against the rounding surface of his body. There

they come, two tiny legs, with five toes apiece, all webbed together. Front legs are growing, too, but they do not show so soon, for they are near the gills and are held within the skin that covers the gills. But feet are not all Little Frog will need in the land life for which he is preparing. He must be able to breathe dry air. Gills will be of no use to him after he leaves the water. So while the legs are growing, the gills begin to disappear and lungs are growing. This is the period when Little Frog in his tadpole stage wriggles frequently up to the surface of the water, pokes his head out, gulps down a little air, and goes back again. He is learning to breathe. For a time he is the possessor of both lungs and gills, but that does not last long. He is about two months old now, and is half made over into a land creature.

LITTLE FROG IS MADE OVER

Now comes the big change. Up to this time Little Frog has been wrapped in the skinlike membrane in which he was born. He has grown, has put out two hind legs, and learned to breathe air. But he is still a big, fat, baby tadpole. He is not a frog at all. Before he can become a frog his head and mouth must be quite changed, as must also his heart and food-digesting organs. He must have a new kind of mouth. But while his mouth is changing, he will not be able to eat. If Little Frog had to stop to figure out a way to accomplish this complete remaking of himself, he would doubtless get discouraged and stay a tadpole all his days. But the magic of life is within him, and he turns this trick as easily as he has any of the earlier ones. He stops eating, and by a channel of blood vessels which makes a circuit through his body he begins to live on his tail. It is a beautiful tail, fat and long, and it serves splendidly as a larder during his fast. And Little Frog need not mourn it, for when he gets to land a long tail would only hamper him. Some lizards who go through a similar process keep their long tails and find them very much in the way of rapid movement. Clearly it is good business for Little Frog to get rid of his tail by so economical a method as feeding on it while his mouth is being made over and his long tongue is growing. Now the skin membrane that has held his body comes off, funny round eyes appear, the new mouth is ready for business, and the fore legs swing out where the gills have disappeared. Little Frog at three months is really a frog, ready to climb out into the air and begin a wholly new life.

FROM WATER TO LAND

Little Frog climbs his own family tree. Watch his tail.

HE JUMPS ASHORE

It is a dangerous moment when he makes the jump from one zone to the other. If he is on the edge of a pond, he can take it in one bold leap, but if he is in deeper water, he must climb out. Once more Nature comes to his help with a special device. For the first few days of his frog life he has a sucking device in his feet, so that he can climb up weeds or walls. It is an amazing fact that a frog in these particular days between his two lives can climb a wall two or three feet high, while a grown-up land-living frog could not climb that way to save his life. Now he must get out quickly or drown. It is curious to think that this little creature, which has spent the three months of its life in the water, can no more live in water than any other air-breathing creature. His gills are gone; his lungs require dry air. There is no turning back on the road on which he has come. So Little Frog leaves his past home, hops ashore, a tiny little frog, about the size of a big finger nail, and begins land life, only returning to the water many months later to lay eggs.

A MOVABLE TONGUE

Of his land life we have stories in Volume III. Before we leave him we should notice one or two more things. He began life eating the soft yolklike food provided for him; he became a vegetarian; then he ate everything that came his way; then he lived for a while on his own body; after that he ate animal matter while he was still in the water; and now on land he appears with the first movable tongue in all the development of life up to his grade, a tongue which is a wonderful insect-catching and insect-holding weapon. From now on he will get his living from insects and slugs, devouring the pests of man's gardens. His last estate with its chosen diet is certainly the most useful for man.

A QUICK-CHANGE ARTIST

As rapid as his diet changes have been his breathing changes, and he has one more "up his sleeve" with which to surprise us. When winter comes, Little Frog hibernates. He retires into a comfortable mud fortress, where he will not be disturbed, and shuts his mouth, his nose, his eyes. His heart beats only very feebly, he eats nothing, and *he breathes through his skin*. Not content with having had gills to breathe through, and with now possessing lungs to breathe through, he has gained or kept a primitive lower-animal power to breathe through his skin when he does not wish to take the trouble or use up the energy to keep his lung bellows at work. Truly Little Frog has been well provided for by Nature. He may make his bow to us, at the close of his exhibition of how life may run through a series of changes, leaving his spectators both well instructed and admiring. He is a quick-change artist if ever there was one. In three months he has "climbed visibly his own genealogical tree."

"What can be more wonderful," says Lydekker, "than the development of the purely aquatic, vegetable-feeding, gill-breathing, limbless, long-tailed tadpole into the amphibious, carnivorous, lung-breathing, four-legged, tailless frog or toad?"

A FROG THAT GETS SMALLER AS IT GROWS OLDER

Only a frog — and a rare one at that — could turn the usual process of life so completely around as to be smaller when it is "grown-up" than when it is young. The very idea is so contrary to the law and custom of life that the proposition sounds like a riddle rather than a sober announcement of fact. Yet there is a frog, the Paradox frog of South America, which never grows to anywhere near the size of its own tadpole. So it is smaller when it is an adult than when it is half grown. The pictures of Little Frog at the different stages of his development show us how this might be. The tadpole with the long fat tail is longer than the baby frog which first hops ashore, but Little Frog grows after he gets ashore. The Paradox frog does not grow. Its tadpole, Mr. Pycraft tells us, is nearly a foot long, with an enormous tail from seven to nine inches long, making up part of that unusual length. That is, its tail alone is longer than the column of printing on this page is high; its head and trunk are meanwhile less than three inches long, or about the width of a single column of type. As the animal "grows" — or

must we say matures? — from tadpole to frog, the tail shrinks away, and the body is quite remodeled, with the result that the adult frog is only two or two and a half inches long. With the ordinary frog this shrinkage is only temporary. With the Paradox frog it is permanent. The adult never grows beyond a length which is a fifth or a sixth that of its own tadpole from which it developed.

FROGS IN POCKETS

The Surinam toad of South America does not dare to trust her eggs to the water. She has developed enough parental instinct to wish to protect them through their infancy. So the father toad helps her to push them up on her back, sixty, seventy, or eighty of them, sticking them into the skin "like currants on the top of a cake." As they sink into the skin and develop, each one is enclosed in a pocket-like cavity with a lid. Here they pass quickly through the development without ever undergoing the water-tadpole stage, and, when they are ready, each pushes up the flap of his pocket and comes hopping out. Here you see a toad which spends most of its time in the water, in or about the flooded forests of the tropics, and yet has developed a land type of care of its offspring.

A JACK-IN-THE-BOX DEVICE

This Surinam toad carries her babies in pockets on her back. When each little toad is ready, he pushes open the lid and jumps out.

THE ADVENTURE OF FLIGHT

The wonder of life, as seen in a flying fish, a frog that lives in a tree, a squirrel that flies, a hedgehog that parachutes — in bats which are the world's champion aviators — in a bird that holds the world's speed record for running — in birds that have lost the power of flight.

SINCE man achieved the art of flying, air travel has taken on a new interest. In primer days we laboriously spelled out the sentence, "Birds fly," and ever since that time when our own observations were first put into words, flying has probably seemed to us to belong to birds and some insects, and to them alone. But now man has learned to fly. Young birds have to learn to fly, too. It may be that flight is not a distinguishing characteristic bestowed upon birds from the beginning of time; it may be that for the lower animals, as for man, flying was a tempting adventure, which many kinds of creatures attempted and in which birds achieved conspicuous success.

Shufeldt after Goodrich

FLYING DRAGON

A tree lizard of the East Indies and southern Asia. Only a few inches long, with a tail twice as long as his body, and "wings" that fold up like a fan.

WHEN FISH FLY

The more we look into this matter of flying from the vantage point of man's very recent entry into the kingdom of the air, the more we take the view that flying was an adventure before it became an art. So many creatures have attempted it. There are the flying fishes, whose front fins developed into a kind of wing. They leap high out of the water, hold these "wings" firmly out, and sail through the air for long distances. Dr. Jordan says that some of them rise from five to twenty feet above the water, and that the larger ones fly for more than an eighth of a mile. It is not true flight. They cannot of their own accord *flap* their wings in the air, although the wings do vibrate. "No force can be acquired while the fish is in the air," writes Dr. Jordan. "The sole motive power is the action under the water of the strong tail." That this movement is very effective any one who has seen a school of flying fishes rise from the water can testify. "When a vessel passes through a school of these fishes, they spring up before it, moving in all directions, as grasshoppers in a meadow."

Flight of this type has been compared to man's flight by means of a parachute. Yet a parachute suggests dropping down from a height. This movement of flying as fish practice it is more like that of an airplane with no engine or a glider. It is gliding or sailing through the air. The amazing thing is that so many different

kinds of creatures have tried it. From fish up, every single type of backboned animals has flying representatives. This gliding flight seems to have been a stage in the attempt to fly which many animals achieved, but at which they stopped, birds and bats alone going on to true flight.

ANIMALS THAT TRY GLIDING IN THE AIR

Frogs tried it, as Flying Frog, here pictured, shows. He lives in Borneo, a tree dweller. He has developed the usual webbed feet of the frog family to such a size that he can fly with them. When he opens them out to their full extent, he has four excellent parachutes which enable him to take the long leaps which have earned him the title of "Flying Frog." If you saw him shooting through the air from one tree to another, you would not stop to question what kind of flight he was practicing; you would exclaim, "See that frog fly!" Wallace tells how this frog was brought to him by a Chinese workman who assured him that he had seen it come down in a slanting direction from a high tree "as if it flew." This was probably the first introduction of Flying Frog to a white man.

Flying Frog keeps his four feet separate, with a parachute of three to four square inches for each. Many of the gliding fliers have folds of skin which go from fore limb to hind limb or even from neck to tail. Draco, the Flying Dragon of the Malay Peninsula and Pacific Islands, is a lizard. Like all lizards he has a snake body, with four little legs on which to carry it; but he has in addition the folds of skin which you see in the picture. With them he can sail or glide long distances. He is the flying member of the reptile order. Flying Squirrel remains to show us that the rodent family became ambitious and attempted flight. Flying Lemur is literally in a class by himself. His flying membrane extends from head to tail with the limbs inside it, as you see when he spreads himself out in the picture on page 43. With it he can sail for one hundred yards or more.

WHEN FLIGHT BEGAN

Wings, whether for true flight or gliding, seem to have developed from or to take the place of front limbs. So they have from the front fins in flying fishes, and from the front limbs in flying squirrels, lemurs, lizards, and many creatures from the other orders of vertebrates. In birds, wings wholly take the place of front limbs. Scientists like to go back of that primer sentence, "Birds fly," and try to imagine the time when flying was an adventure to be undertaken.

In this book we are more concerned with facts than with theories. We are picturing "The Wonder of Life" as it is to-day. Yet we need not shut ourselves out from some of the more interesting ideas about how things came to be as we find them, any more than we shut ourselves out from stories of cave men and Indians and wild beasts that roamed our American plains before ever a red man or a white man gazed upon them. But when we read these science stories of how things came to be, we should remember that they are stories — true ones, very likely, but still only stories worked out by very clever men from the facts as they find them to-day. The life of birds and beasts and fishes to-day is all that we can know. Only the Master Mind of the Creator, the God who was in the beginning and who created the

From R. W. Shufeldt

WALLACE'S FLYING FROG OF BORNEO

For a body four inches long this tree frog has on his four feet a combined web expanse for parachute use of twelve square inches. No wonder he can glide long distances.

heavens and the earth and all that in them is, knows in what order and in what times these wonders came to be. When we talk about how the adventure of flight began, we are not saying, "This happened in this way": rather we are trying to spell out and read backward from the present some of the marvelous facts that are surely written in the records of life as it has been lived on this planet. This is a serious introduction for a very simple story, but every reader

Shufeldt after Oldfield Thomas

AN UPSIDE-DOWN CREATURE

Turn this page upside down. Then this bat will look as if he might be standing on the branch. No, he is hanging comfortably by his feet, head down.

should know the spirit in which these stories and theories about the past are occasionally offered. They are "grown-up" versions of the "Once upon a time" stories of our childhood.

As to the adventure of flight as it was first attempted, the scientist says, did these bold pioneers, the would-be fliers, first jump up or first jump down? It sounds like a child's riddle, but it has been considered important enough for learned men to divide into two schools of opinion on the matter. One group pictures the "about-to-be bird" as running along the ground, leaping again and again into the air and waving meanwhile his fore limbs vigorously. Finally, according to this version of the story, as a result of this strenuous effort those front limbs become wings! The others, among whom are Dr. Frederic A. Lucas and Dr. William Beebe, picture the "about-to-be bird" as already up in the trees and as spreading out his fore limbs to catch at anything which would break the fall or to get any support he could from the air in his long leaps. Using his fore limbs in this way, he gradually developed wings which he learned to use for true flight. If birds were the only creatures that flew, there would be no means of surmising how flight began. Since there are all these flying creatures of whom we have been speaking, which have apparently stopped part way on the road to flight, it is their living evidence that counts. They all glide downward, and most of them live in trees. So Dr. Beebe thinks that since he can show every stage of the practice exercises in an animal that stopped at that particular stage, he has proved his point that the adventure of flight was made from above, that the "about-to-be bird" jumped down and that wings like parachutes were to delay the final sinking into the water or dropping to the earth.

BATS THE WORLD'S BEST FLIERS

Bats are the living proof that true and successful flight can be achieved outside the bird family. They are the bond between the lower orders of fliers and the birds. Like the gliders, they have fore limbs and hind limbs connected by or enclosed in a huge skin membrane or wing. Unlike the gliders they use these wings as the birds do theirs; by means of them they sustain themselves in the air through their own muscular effort, and alter their direction or change their altitude at will. The bat is the only mammal that flies.

Bat flight is no poor makeshift at flight. Dr. Shufeldt tells us that bats are among the most remarkable fliers in the world. "With due consideration for all of its [bird-flight's] varied

THE BAT—THE WORLD'S CHAMPION AVIATOR

Shufeldt after Oldfield Thomas

BAT LIFE A PERPETUAL SOMERSAULT

The bat is the only mammal that flies, the only creature except birds and insects that practices real flight, not parachuting or gliding. Above: Flying fox of Australia. Below (left): Woodford's fruit bat; (right): Giant fruit bats from Solomon Islands. The one in front is hanging by his "thumbs," the one behind by his feet.

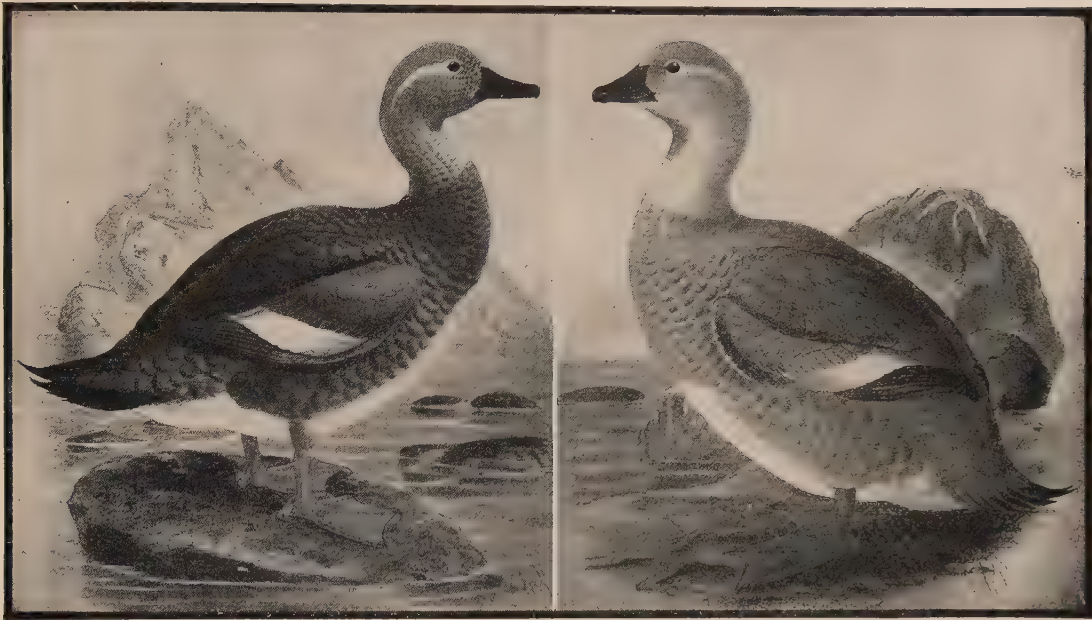
kinds, there is no single bird, apart from its possessing great power of flight in a straight line or in a more or less curved one, that can, in any way, compare with the remarkable flying accomplishments of any of the smaller bats of the world or, presumably, with the big ones either." Take our common little brown bat of the eastern United States. It cannot fly with the rapidity of the teal duck, which goes with extraordinary power and rapidity, but when it is out on its quest for the evening meal, "no bird living can, in flight, in any way equal its movements; . . . in its efforts to seize its prey, this little winged entomologist of the air shoots about, tumbles and twists, darts hither and thither, flits in beautiful curves." Bats are so well fitted for life in the kingdom of the air, so also the least terrestrial. Birds and insects are much more adapted to progression on the ground. Bats can fly; they can hang upside down and right side up; they can swing head up or head down, holding on by fore limbs or hind limbs; they can sleep head down; but walk they cannot. Dr. Shufeldt took our photograph of a bat trying to walk or crawl on a table top, to show what a hard time he makes of it and with what awkwardness he hitches along. More than any other animal he was made for the air, and in the air he belongs. The mother bat goes so far as to carry her family with her in the air. She has only one or two baby bats at a time, and these tiny, hairless little things cling from the day of their birth to the hair of the mother's breast, while she flies about as usual. It is the

Photo from life by R. W. Shufeldt

BROWN BAT TRYING TO WALK ON A TABLE

The bat can do anything in the air. He can hang head up or head down. But on a flat surface he is almost helpless. The only thing he cannot do is to walk.

completely the masters of this third and least inhabited zone of life, that they are by their entire make-up unfitted for life on the ground. The most perfectly aërial of all animals, they are Indian mother and papoose arrangement made permanent until the little bats are big enough to shift for themselves. When she is not flying and can fold her great waterproof wings about them,



From R. W. Shufeldt

AN OBJECT LESSON IN LOSS OF FLIGHT

The young steamer duck, at the left, can fly; the adult duck, at the right, has lost this power, but has remarkable speed as a swimmer. Steamer ducks are sea fowl of Patagonia, Tierra del Fuego, and the Falkland Islands.

they are well protected, as is she, from wind and weather.

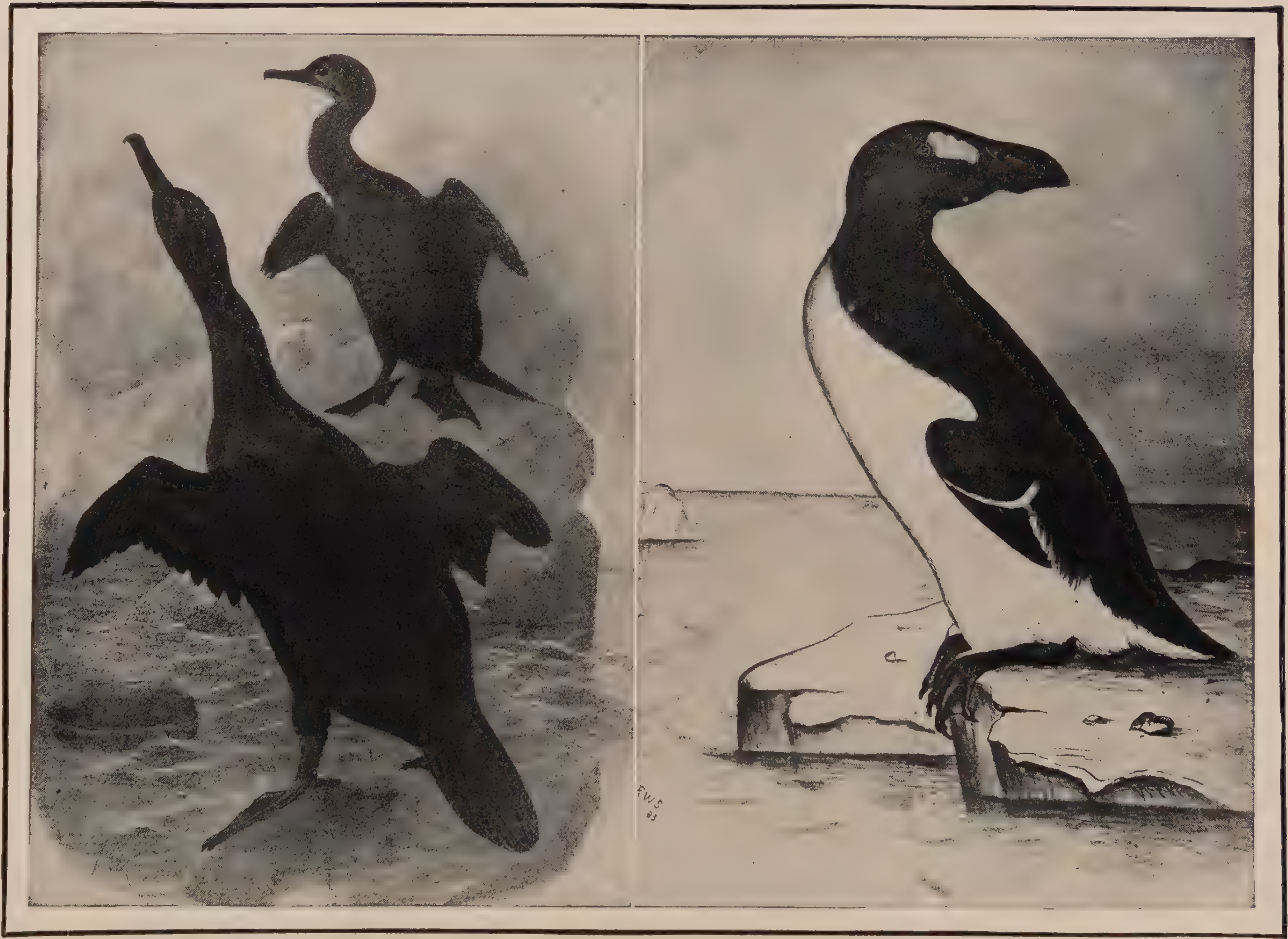
BIRDS WHICH CANNOT FLY

Flight is by no means a universal characteristic of birds. There are many birds which do not and can not fly. Ostriches, cassowaries, emus, penguins, kiwis, and others of the larger birds are flightless, and there are, as we all know, many birds like ducks, hens, etc., which are but indifferent fliers. All these make chapters in the scientist's story of flight as an adventure. Some have traces of wings, others wings in all stages of development. We have photographs here of a member of the duck family: the younger bird, at the left, has larger wings in proportion to its size than the adult bird facing it, which has taken so completely to water life that it has not developed its wings for flying. Evidently if one desires to keep the power of flight for oneself and for one's children's children it is well to make use of it.

While we are talking of zones in which life is lived, there are some surprising facts to notice. Bats are little animals, not birds; yet they are among the most wonderful fliers of the world. Now we come upon the singular fact that the ostrich, a bird, is perhaps the most rapid terrestrial animal. It is the largest of existing birds, is flightless, yet can get over the ground so fast on its long legs that it can outrun the swiftest two-footed or four-footed animals. A single stride is said to cover frequently twenty-five feet or more, and when it first sets out to run it sometimes attains a speed of sixty miles an hour. If its wits equaled its powers of locomotion, it would leave all enemies behind; but the youngest school child has learned from his geography of its silly habit of running in a circle, which allows its pursuers to cut across the area which its track will enclose, and meet or overtake it though going at a lesser speed than that at which it is running. Ostrich wings are useless as organs of flight, but they can be used as sails to add to the speed of the ostrich as he runs.

OTHER RAPID RUNNERS AMONG FLIGHTLESS BIRDS

The ostrich stands seven or eight feet tall. Next smaller than he in the bird family is the



By R. W. Shufeldt

THE GREAT AUK

FLIGHTLESS CORMORANT

The great auk is a famous flightless sea fowl of the North Atlantic seas, extinct in the middle of the nineteenth century. The flightless cormorant is nearly extinct.

emu, which stands over five feet high, and lives in the deserts and on the plains of Australia. In it and the cassowary, to which it is closely related, we see the characteristic loose plumage of the flightless bird. The feathers are slender and drooping, more like hair than like the stiff quills of most birds. The cassowary has a peculiar brightly colored helmet which can be seen on page 65. Both birds are swift runners and strong swimmers. The emu chick is an excellent example of protective coloration, its black, grayish, and white stripes blending with the grass in which it hides. Here we see the family out for a stroll and get an idea how curious these flightless birds of the other side of the world are in their appearance.

Photo by E. R. Sanborn, New York Zoological Society

EMU WITH YOUNG

This Australian bird has wholly lost the power of flight. It stands over five feet high and is next smaller than the ostrich, which is the largest existing bird. It has slender, drooping feathers, but hardly a trace of wings.

HOW THEY VANISH FROM THE EARTH

Within historic or near-historic periods many flightless birds have become extinct. It is sad to think of any species of animal, developed by Nature with wonderful care and minuteness, disappearing completely and forever from the earth. Yet this performance has been repeated times without number for countless ages. Every geologic age had its own animal and plant life, and of many of them we have only a few fossils left from which to make our mental picture of a period when giant monsters walked our plains, when reptiles flew, and sea creatures climbed out of the watery depths to solid footing on Mother Earth. Of the passing of birds and animals because they were unfitted to contend with natural conditions we think with only a scientific and curious wish that we might have seen them before they disappeared from the face of the earth. But of the passing of birds and animals through the presence and activities of man we must always think with a deep regret, almost with a sense of personal responsibility. In our own time statesmen and naturalists have been able to impress upon the public the shame and waste of an extinction of any of the wonderful products of animal life through mere carelessness or wanton destructiveness. Government parks, bird sanctuaries in mid-ocean,

closed seasons for game protection, are among the provisions which attempt to stay the destructive tendencies of human civilization upon wild life. Any and all measures which have this bearing should have the interest and active support of every man, woman, and child as a part of good citizenship. The keeping up of the balance of Nature makes for safety from a multitude of ills of which famine and pests are conspicuous examples.

It is not surprising that flightless birds are first to fall victims to natural causes of extinction. In giving up the power of flight, as a means of escape, their ancestors gave up a powerful instrument of self-protection. Of some of those which have disappeared in recent times we can see pictures and find accurate descriptions. The "great auk," a sea bird two or two and a half feet long, lived on the coasts of the North Atlantic seas, coming south as far as Massachusetts. Less than a century ago there was a colony of several thousand, but men exterminated them for their ship food and the last living auk is believed to have been killed near Iceland in 1844. One of the cormorant group, finding flight of no special value, gave up the use of its wings for that purpose. The wings became smaller and smaller from generation to generation, and that species, too, has disappeared from off the face of the earth.

THE DODO

The dodo is the most familiar example of bird extinction, for its disappearance was known in

From R. W. Shufeldt

THE FAMOUS LONG EXTINCT DODO

There were thousands of dodos in the early Middle Ages, but by 1700 or 1750 they had vanished from the earth. This drawing is the old familiar, imaginary drawing of the Réunion Island dodo, sometimes called the "solitaire."

Europe and England in the seventeenth and eighteenth centuries and was the occasion of many references to it in poetry and prose. All your life you will be running across references in standard literature to the dodo. The bird we have chosen to show in the photograph is the dodo of Réunion Island, a neighboring island to that of the Island of Mauritius, where the dodo of dark plumage (familiar in the single picture of it so frequently reproduced) was observed. This Réunion Island dodo disappeared later than its darker-colored relative, but is of the same style and build. Both have completely disappeared. The first written description given of the dodo was published in Amsterdam in 1601, as it was reported from the voyage of a Dutch admiral. It had vanished from the face of the earth before a century had passed. "The total inability of flight," says Rothschild, "the heavy, slow gait, and the utter fearlessness because of immunity from enemies, led to a continued slaughter for food by the sailors and others who came to and dwelt on the Mauritius. But the final cause of extermination of this and many other birds in the Mascarene Islands was probably the introduction of pigs, and also of the Ceylon monkey. These animals increased enormously in numbers, ran wild in the woods, and soon destroyed all the eggs and young birds they could find."

They are curious in appearance, all these flightless fowls, because bodies are overdeveloped at the expense of wings. But of what gain were wings when one inhabited a luxuriant tropical island with food at hand to supply every need and no larger creature as a fellow inhabitant which interfered with one's comfort and safety? Wings might very naturally have seemed to be an actual incumbrance until men and pigs arrived; then they were needed for escape, but were gone.

THE IMPULSE TO FLY

If wings can become so small as to be useless for flight from long disuse by successive generations; if they can fail to grow even when they appear, as in the flying young steamer duck and the flightless adult steamer duck; if they can be developed by animals as fanlike folds of skin; if they can take the place of the front fins of a fish or the front limbs of a bird — then surely flight may be looked upon as one of the great adventures of life as it has been lived by the animal creation. Wings as the instruments of flight are marvelous pieces of machinery developed to meet a need or desire or hidden pressure of life, that the zone of the air should not remain untenanted. Birds did not fly because they happened to have wings; wings came in response to an inward impulse to fly.

IN OTHER WORDS

"The flight of all bats is ideal; their mastery of the air is perfect; far better, indeed, than that of most birds, I am almost tempted to say than that of any bird. Nothing but recollections of swallows and falcons restrain the phrase. In one way at least the bat excels even these — its flight is absolutely silent. It skims and darts and turns within a foot of one's head, but never a swish of its wings is heard. . . . Its envied conquest of the realms of the air seems the bat's most wonderful gift, and yet more marvelous, though less spectacular, is its astonishing sense of touch, which, perhaps more often than its eyes, averts the wreck and ruin that impetuous flight in gloomy woods might bring. . . .

"The bat is one of the masterpieces of creation. It exemplifies, in high degree, the perfect beast with perfect senses, equipped with perfect flight, so there be few indeed that in the scale outrank it." — Ernest Thompson Seton.

BIRDS THAT FLY UNDER WATER

WE have seen animals crawl out of water to live on land; we have seen animals develop wings that they might inhabit the kingdom of the air; now we come to a bird which has given up its life in the air for a land and water life. Many flightless birds have done this to a certain extent. The penguin is conspicuous in that it is more at home under water than on the surface of the water or on land.

On land the penguin stands erect like a man, with the front flippers hanging like arms. A group of these birds, some species of them three feet tall, standing on the beach, as they do in the picture, present from a distance a curious, almost human appearance. But when they try to walk, the effect is laughable. An observer has spoken of their "toddling on the ice like top-heavy babies." The short legs with heavy seal-like bodies atop them make motion clumsy and rapid motion almost impossible. "No living thing that I ever saw," writes Kidder, "expresses so graphically a state of *hurry* as a penguin, when trying to escape. Its neck is stretched out, flippers whirling like sails of a windmill, and body wagging from side to side, its short legs making stumbling and frantic efforts to get over the ground."

Let the penguin but reach the water and dive into it — "the moment it has plunged below the surface it is transfigured. With short rapid

Photo by Rollo H. Beck

RESTING PENGUINS, EAST FALKLAND ISLANDS

"During the summer season many of the penguins that are not nesting come ashore and spend hours on the beach, a short distance above the water."

strokes of its paddle-wings it darts through the water," writes John Lea, "leaving a trail of glistening bubbles behind, and shoots forward with the speed of a fish, turning more rapidly than almost any bird of the air by strokes of the wing alone, the legs floating apparently inert in a line with the gleaming body, or giving an occasional upward kick to force it to greater depths."

Penguins do actually fly under water, using wings to propel them in almost exactly the way that a bird uses its wings in the air. After all, water and air are not so different. Both are fluids, the one gaseous, the other liquid. A solid body which can move through one medium is likely to be built on lines which adapt it for motion in the other. The projecting edge of the bird's breastbone is always spoken of as the keel because it so resembles that part of a boat and because it serves the same purpose. Ducks use their feet for swimming under water. Penguins use their wings, which have been so transformed that they are like the flippers of seals or whales or like the fins of the larger marine animals. "The outline of the wing is exactly like that of a shark's fin," writes Beebe, "the flatness and breadth including even the bones, while (also like a fin) all of the bending quality of a wing is lost,— all the flexibility of wrist and elbow. . . . As in the ostriches, the relics of flight feathers have increased greatly in number, but have become small and scaly. . . . Instead of a given number of feathers, divided into well-marked series, the paddles of a penguin are covered thickly with small feather-scales." It is Dr. Beebe who has called penguins "the most wonderful birds in the world," partly because of this history which they suggest. At some time they may have been water creatures. Then they may have come ashore and developed front fins into wings. Now the wings are again like fins, and the birds *walk* on land and *fly* under water.

Photo by Rollo H. Beck

ROCK-HOPPER PENGUIN, MOTHER AND YOUNG

"The rock hopper is an odd-looking fellow, clothed in slate-gray and white, with a bright red bill and erectile head plumes of sulphur-yellow."

A MAN IN FISH WORLD

How it feels to become "a fish among fishes" — the experience of Dr. W. H. Longley, Professor of Biology in Goucher College, in the course of researches conducted at Tortugas, Florida, under the auspices of the Carnegie Institution of Washington, as told by himself and illustrated with pictures taken by him under water.

DR. LONGLEY spent the greater part of a summer moving about in Fish World, sitting, standing, walking, taking photographs, as you see a man doing in the picture. Fish World is not far away. It is at our shores; it is beneath our boats and our canoes. Yet how far away from our experience it is! "Few parts of the world seem at once so safely accessible and so little known as certain parts lying in water less than twenty feet deep in tropical seas," wrote Dr. Longley, in the first story of his life underseas which came to our notice. "No one," he continued, "who has not clothed himself in some sort of diving equipment, clambered over and among the corals, and explored as best he might the labyrinth of passages they enclose, and measured his own height against theirs . . . really knows the reef as it is." So Dr. Longley became, in the words of a fellow scientist, "a fish among fishes."

Putting on the diving helmet, which enables the diver to breathe under water and yet is not cumbersome as the usual diver's suit, he explored the coral reefs at the Tortugas, in Florida, using as his headquarters the Marine Biological Laboratory of the Carnegie Institution of Washington situated there. For hours of each day and for weeks at a time he lived among the reef fishes, carrying a camera in a specially devised watertight metallic box and taking the pictures which he gives us here. To take pictures in Fish World is a wonderful achievement. Many fish pictures have been taken in or through the glass tanks of aquaria, but these are under-water photographs of the fish in their own natural surroundings.

When we wrote Dr. Longley asking him if we might have these pictures to show to our readers, he wrote back that he would be glad to send them, adding, "I may say with complete truthfulness that your WONDER WORLD will be the first volume of Natural History to contain such pictures of fishes in their native environment." Before we come to the story he sent with them, telling his purpose in going through this unique under-water experience, let us see by what mechanical means his achievement was made possible.

HOW IT WAS MANAGED

The diving helmet, shown in the photographs,* is a barrel-shaped brass hood with a conical top and a handle so that it may be easily put on or lifted off. It has a front plate-glass window through which the diver may look. To the back flap are attached masses of lead to overcome the natural buoyancy of the diver and hold him firmly on the bottom. Only the weight of the helmet keeps the man from "being driven to the surface like a shot." Into the helmet is fastened a rubber hose which runs to the surface of the water. If you could see the surface of the water directly above this diver, you would see there a boat. The hose is connected with a double-cylindered hand pump worked by a long lever. The man in the boat keeps an air supply going down. In the right-hand picture you can see how the air which has been breathed and the excess of air pumped down escapes from under the hood and rises in a stream of bubbles. Thus equipped the diver is free to move about as he pleases.

A DIFFERENT WORLD

It is a different world into which he has come. "The observer at the surface of the

* The helmet used is the Dunn diving helmet, which has been a part of the equipment of the Marine Biological Laboratory at the Tortugas, Florida, since 1915. The photographs on the opposite page are reproduced through the courtesy of the Miller-Dunn Company, Miami, Florida.

A MAN UNDERSEAS IN FISH WORLD

Submarine Photo Co., Miami, Florida

STUDYING FISHES AT CLOSE RANGE WHERE THEY LIVE

water," wrote Dr. Longley in the *American Museum Journal*, "sees what lies below in little more than two dimensions. From his position he fails further to comprehend the conditions under which the reef population lives, for water appears to him to be essentially colorless crystal, which blurs no outline, and less, crystal clear, and unsubstantial. Darkening with depth, its soft tints are all pervasive. It blurs and softens every outline. Except when the light is strongest and it is itself most free from sediment, it denies one sight of all but immediate surroundings, and resolves one's world into a diminutive hollow hemisphere,

Photo by W. H. Longley

IDLING AWAY THE DAYLIGHT HOURS

"Numerous yellow grunts and a white grunt schooling about a clump of gorgonians and flanked by a massive coral head. These are fishes that feed almost wholly by night, and are characteristically given to idling away the daylight hours. Despite their plantlike appearance the gorgonians are animals, as is also, of course, the great coral. Thus every conspicuous feature in the picture is animal, where on land animal, vegetable, and mineral kingdoms would be required to participate in giving the same general effect."

in which to hide would seem impossible. But when, covered with water, he stands upon the bottom, he speedily realizes how imperfect is his knowledge of the ground he may have studied from above until every detail seemed familiar, and how significant are the changes induced by substituting a very dense for a rarer 'atmosphere.' . . . Over all there hangs a veil of mystery. The water is no longer color- filled with silence, and on all sides fading into nothingness."

In our story of protective coloration we have taken note of the fact that many species of fish can change color at will. The fishes of tropical reefs are brilliantly colored. It was to study this subject of fish coloration that Dr. Longley made his exploring expedition into Fish World. In the remainder of this chapter he tells us of

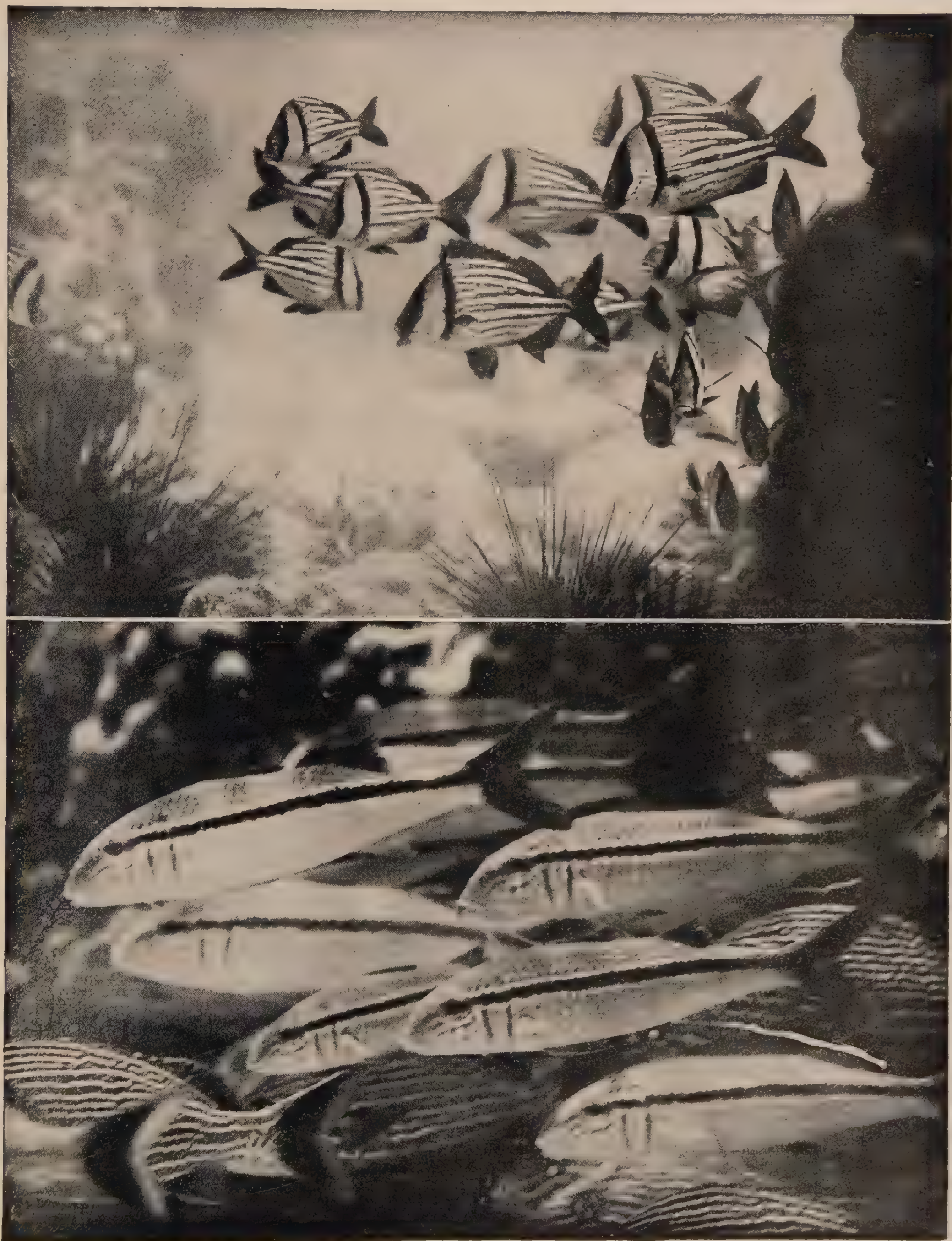
HOW A FISH CAN CHANGE HIS APPEARANCE

Photos by W. H. Longley

CAMOUFLAGE AS PRACTICED BY FISHES

"This power of changing color and color pattern is common among fishes and appears to be serviceable chiefly in enabling them to duplicate upon their own bodies the color of their surroundings, and so to be less conspicuous in the eyes of possible enemies. The mottled fish is among dark objects and over rough bottom in which there are many dark shadows. The pale gray one is above a bottom of fine white sand. Both are feeding. Either might become like the other if it were to change places with it."

FISHES PHOTOGRAPHED BY MAN ON SEA BOTTOM



Photos by W. H. Longley

FISHES IN SCHOOLS AS THEY PASSED BY

Above: "Porkfish schooling about a coral head. These fishes feed almost wholly by night. They are about six inches long, as are also the piercing spines of the sea urchins sheltered in the rock crevices beneath them." Below: "Yellow goatfishes and **yellow grunts schooling together about corals."**

the results. From this point the story is in his own words as he wrote it for us.

THE PROBLEM TO BE SOLVED

"What use, if any, the colors and color patterns of animals possess has been the subject of much discussion among zoölogists. It is agreed that under natural conditions they seem in many cases well suited to conceal the animals that display them, whence these creatures are said to be protectively, or better, obliteratively colored. But there are many other animals whose bright colors in strong contrast with one another seem to have quite the contrary effect, and to render the animal displaying them particularly conspicuous. Whether the animals in question gain any advantage from conspicuousness is a matter in dispute. Some students of the problem think, for example, that the bright colors may advertise their possessor's unpalatability; others find no evidence that they are of use at all.

"Tropical reef fishes include many bright-colored species. They are abundant and easily approached for purposes of study by any investigator who cares to go among them in diving dress. It seemed probable that knowledge of their habits and the relation in which they stand to their surroundings might cast some light upon questions of long standing. Hence the research was undertaken in connection with which the accompanying photographs were secured."

Photo by W. H. Longley

GETTING A MEAL

"A yellowtail is hovering above a red goatfish, which is feeling about in the sand for food. The yellowtail is prepared to seize any shrimp that may dart away in alarm at the touch of the goatfish's fluttering barrels. A slippery Dick is in the foreground, a second goatfish in the middle distance, and a parrotfish farther away than any of the others."

ON GOING UNDER WATER

"One has mingled sensations upon going down for the first time among the marine creatures, even in water no deeper than ten or fifteen feet.

"It is only upon rare occasions that one can see even indistinctly under water for more than fifty feet, and commonly the visibility is much lower than that statement implies. Since it is not possible to look out from the water into the air on account of the reflection of the light rays from the under face of the surface film of the water, one is likely to experience a feeling of complete isolation which is by no means enjoyable. For one is not only isolated, but clumsy and essentially helpless. The strange, exotic beauty of one's surroundings inspires one, however, and offsets any feeling of uncertainty and unrest one may have as to what lies at any moment just beyond the range of vision. The horizon is so near that the blue canopy of heaven seems no larger than a tent, but a tent within whose confines may lie a veritable fairyland."

LIFE AS ONE SEES IT

"One may sit still or ramble about for hours without coming to the surface, hours all too few to examine closely the strange things to be observed on every hand. There may be sea fans and other gorgonians standing like clumps of shrubbery; corals, massive or branching, yellow, buff, brown, green, or olive; sea urchins and sea cucumbers; basket stars, squids, octopuses, crabs, shrimps, lobsters; and fishes innumerable.

"The latter are of almost every conceivable habit. They are carnivorous and herbivorous; nocturnal and diurnal; surface haunters and bottom dwellers; fishes that range widely or whose widest excursions are only a foot or two from the burrows they appropriate, or dig themselves in sandy bottoms; fishes ever alert and active, sluggish and inert, or even clinging limpetlike to rock surfaces or to other fishes."

WHY THE BRIGHT COLORS OF FISHES?

"But to return to the fruits of the main purpose with which the descent was undertaken, they were these. When the bright-colored reef fishes are closely studied it appears that their colors are upon the whole well adapted to diminish their visibility under the average conditions in which they live. The more nearly the ranges of the different kinds agree with one another, the more closely those kinds resemble one another in color. The more closely confined to a particular type of surroundings a species is, the more clearly it repeats the typical colors of the place it frequents. And finally, in many species the individuals have large powers of instantaneous color change, which in so far as they have been investigated appear to be exercised chiefly in such a way as to bring the creatures into color agreement with their surroundings as they move from place to place.

"In short, it appears that in spite of apparent improbability the bright colors of the fishes are obliterative, and their whole coloration a naturally developed system of camouflage."

DEEP-SEA LIFE

A mystery of life — how tiny fishes live under a pressure of four tons of water — of a world that is freezing cold and utterly dark, yet dwelt in by plants and fishes.

DR. LONGLEY has helped us to a realizing sense of the complete change of environment resulting from going down into Fish World fifteen or twenty feet. It takes almost more imagination than any one can conjure up at a moment's notice to make any mental picture of life fathoms deep in those lower regions of the sea where man cannot yet go. The scientist has for long years studied the fishes brought up from these regions by dredging and the conditions of their life as it may be inferred from similar life which we do know. With him as interpreter we can try to enter by imagination into this "cold black world where night reigns supreme."

Deep-sea life is lived under an enormous pressure of water. We are told that the air, the atmosphere above us, is pressing down upon us with a weight of fifteen pounds to the square

inch. Yet no one of us is conscious of any pressure or of any weight of air above our heads. A man cannot go down very far into the sea without being overcome by the weight and pressure of the water above and around him. The heaviest metal diving suit will be knocked in as if by a sledge hammer by the pressure of the water. If we followed out our own first thought as to how the fishes of the deep sea, that have thousands upon thousands of pounds of water pressing down upon them, would naturally be formed, we should have them like the trunk fishes, only more heavily encased in a wall of stiff resisting shell. Yet of what use would such a shell be when the heaviest piece of glass which can be devised comes up ground to powder after having been let down into these regions? Nature has found the answer to the problem, and it is one of which we should never have thought. The bodies of these deep-sea fishes are very tender and soft, loosely knit together. They are merely tissues containing a large amount of fluid. So the very liquidity of their bodies, the fluid within pressing out while the fluid without presses in, is what enables them to keep their shape. When these fishes are brought to the surface of the water, they frequently burst. The removal of the pressure from without lets the gases within push the soft walls of tissue away. But with what has been calculated as four tons of pressure to the square inch bearing down and about upon them, these small fishes live out their lives, as little hampered in their movements, as unconscious of it as are we of a pressure above and about us of fifteen pounds to the square inch.

Would our bodies be smaller if we lived under higher pressure? It seems probable that they would, as most deep-sea fishes are small, only a few inches long. Would our muscles grow more soft and flabby, our bodies more like gelatine, the "heavier" the atmosphere about us? It seems probable. If we went up into the air and lived under less pressure, would our bodies be larger? It may be. The whale, the largest water dweller, is a surface mammal and an air breather. The angler of the British Channel is many, many times the size of his deep-sea cousin. These questions start interesting trains of thought. Men on Mars should, by analogy, be larger. The atmosphere there is apparently less dense. Men on Jupiter, Saturn, Uranus, and Neptune would, by the same reasoning, be smaller, their size varying with the density of the atmosphere. The more we consider life as it is lived in our own zone, in the air immediately surrounding the earth, the more we realize its wonderful and unchanging fitness for our lives. A little change of pressure, a little variation of temperature, and all would be changed. Taken as it is, under the wise protection of natural law, it is eminently satisfactory.

STRANGE CREATURES OF THE DEPTHS

They are queer little specimens, these creatures of the fearful ocean depths. There is no growing vegetation of any sort in these cold, black regions where no sunlight ever penetrates, and where the temperature is within a few degrees of the freezing point. The fishes prey on each other, and on such smaller animal life as exists in the water. Many of them are ferocious-looking creatures with their huge teeth, wide mouths, and enormous stomachs. Meals are likely to be infrequent, so they are built to get a big supply when they can. Some have been pulled to the surface which had swallowed and accommodated in their expansive, bag-like stomachs fish larger than themselves. "But," as J. Arthur Thomson has well said, in his suggestive discussion of "The Haunts of Life," "since they cannot all be eating one another there must be some extraneous food supply. That is afforded by the gentle and ceaseless rain of small organisms, killed by vicissitudes in the pelagic meadows overhead, and sinking through the miles of water like snowflakes falling on a very still day."

There are many interesting adaptations to their life which are easily traceable in the fishes of the ocean depths. The heat from the sun is lost far above them, at perhaps 150 fathoms, and hardly any sunlight penetrates beyond 250 fathoms. So there would be total darkness, were it not for the fact that many deep-sea fishes carry their lights with them. They have luminous organs which give out light. The anglers wave a lighted bulb in front of them, apparently as a bait as well as a torch. Other fishes have rows of lights all over their bodies. Of these we shall speak more fully in the story of

"Living Lamps," where are shown also pictures of these deep-sea creatures. Here we mention them to complete our picture of this strange, remote world, dark, yet lighted by the silvery flashes of luminous fishes darting on their quests for food (though many of the fishes are so nearly blind that they can have little clear vision of their neighbors), cold with a steady cold which is unvarying, silent with a stillness which is never broken from without, yet for all its apparent disadvantages the home of a richly varied life.

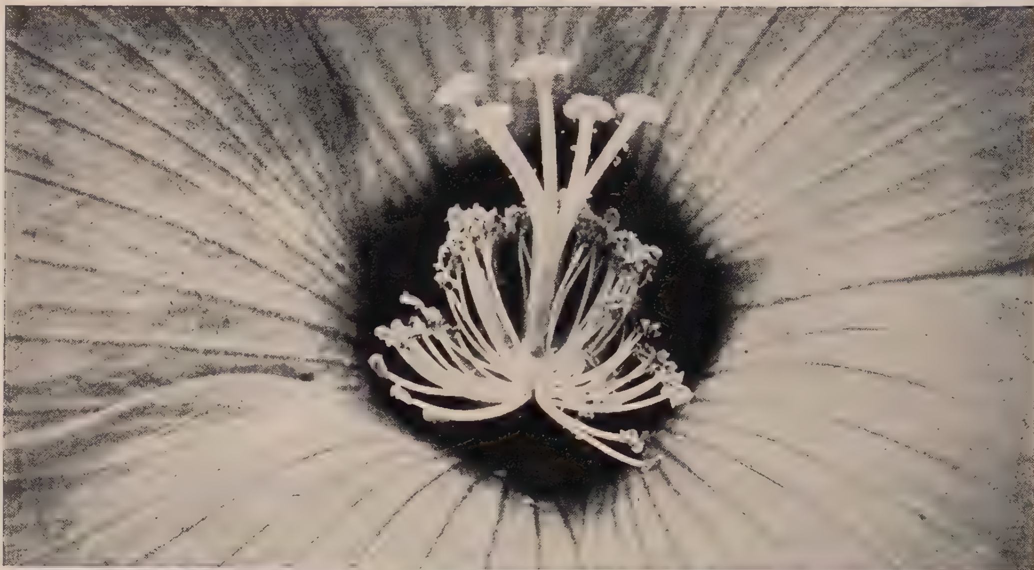
Life might have passed this region by; instead it populated it with representatives of almost every class of sea animals. No zone was too deep for life. "There is perhaps no more striking modern gift to the imagination than the picture which explorers have given of the eerie, cold, dark, calm, silent, plantless, monotonous, but thickly peopled world of the Deep Sea," writes Dr. Thomson as he discusses the significance of this life group. "Yet this cannot be its full meaning. Perhaps we get nearer the heart of the problem when we recognize the simple fact that the Deep Sea is an integral part of the whole. Just as the making of the great 'deeps' was correlated with the raising of great mountains, so the abyssal fauna is wrapped up with the whole vital economy of the Earth. For it is the overflow basin of the great fountain of life whose arch is sunlit. It is necessary to the wholesomeness of the ocean. It is the universal clearing house."

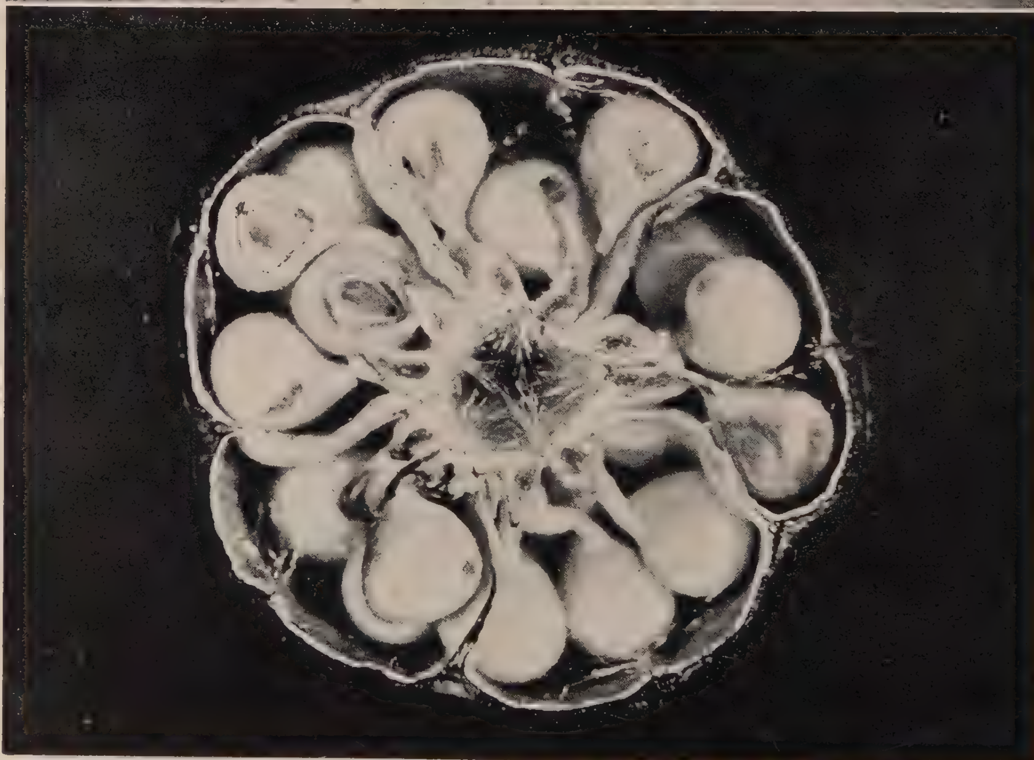
Courtesy of American Museum of Natural History

DEEP-SEA FISHES

Models from fishes which have been brought up from the depths of the ocean, as shown in the American Museum of Natural History, New York. (See also page 239.)

THE BIRTH OF A PLANT





THE MALLOW FLOWER, SHOWING STAMENS, PISTILS, AND SEEDS *Photos by E. F. Bigelow*

Look into any flower, as here you look through the magnifying glass into the mallow flower, and you will find within the protecting petals a group of stamens, each with a "dust box" at the end holding flower dust or pollen, and close to them a group of pistils, stalks with seed boxes at their lower ends. When the flower dust drops into the seed box, the seed begins to form. Below you see how seeds are packed in the mallow pod.

Photo by Wm. L. Finley and H. T Bohlman

CHICKS OF WESTERN GREBE, JUST OUT OF EGG

LIFE THE MASTER BUILDER

The secret of life, its magic touch — of a creature that walks without legs, eats without a mouth, breathes without lungs, feels without nerves, cuts itself in two and becomes two creatures.

LIFE-STUFF, the material life has to work with, is the same the world over. It is the same in plants and animals. This is one of the marvels of the world, that all living things are built on a single pattern, the pattern of one cell upon another. Life does not work with matter in big chunks. It makes its big structures out of millions of tiny structures. It takes a cell, a tiny walled-off bit of matter containing a gray, colorless fluid, and with that cell as a unit it builds an infinite variety of forms. We have read how many hundreds of cells there are in a short piece of hair. Such stories might be repeated indefinitely. We shall come upon them when we talk of the structure of the human body, or of the blood, that river of life upon which float millions of corpuscles. Our present marvel is the simplicity, yet the amazing complexity, of the cell which life, as master builder, uses with such a variety of results.

THE MAGIC TOUCH

When I was a child I had for a plaything a wooden egg which opened. When the two halves of outer shell were pulled apart there lay within them a smaller egg, gayly colored in reds and blues. That, too, could be opened, and within it was a smaller egg, and so the process might be repeated until finally when twelve or fifteen shells had been taken off there lay within the innermost shell a tiny egg, no larger than the head of a good-sized pin, *which would not open.* That little egg looked like the others, but it had its own secret. I never knew what was inside it.

When wise men search for life within an egg or a plant or an animal, they do something very like what I did with my plaything. They strip off one layer after another. At last they come to the single cell, with its fluid contents. Here they stop. They can look at it, they can test it,

they can find out some of the elements of which it is composed. But it has its secret which they have not learned. The fluid is made of chemicals, of the same elements which make non-living matter. They can almost find out its formula, although it is so complex that they have not yet quite achieved it. But if they found out its exact formula, still they would not have its secret, for they could not make out of the same elements something exactly like it. This is because it has received the magic touch of life.

LIFE-STUFF, OR PROTOPLASM

Living matter has its own secret, which has never been unearthed. Every little while we read in the newspapers that some one has succeeded in making out of chemicals a bit of living matter; but this has never proved to be true. There has always been some bit of living matter concerned, or else the new product has not life. Life comes only from life, and life has its own creative secret, its own magic touch. This touch it gives to the life-stuff, the fluid, in the tiny cell. They call this fluid "protoplasm," which means "first form" or "first stuff," for it is the substance with which life works. Strip off all the coverings and wherever life is, there is found this fluid. It is sensitive stuff. If the temperature is raised too high or dropped too low, the life will go out of it and it will be lifeless matter again. But for the time being it is alive, and being alive, it can work wonders.

WHAT LIFE CAN DO WITH A SINGLE BIT OF MATTER

We have spoken of cells as having cell walls. All cells do not have walls. The amœba, of which I want to tell you in order to show you what magic this touch of life can work, is a mass of protoplasm without even a cell wall, though it is densest on the outside. Yet it is a separate animal, with characteristics all its own. It has a separate rating in the class of Protozoa, or first animals, of which you read in Volume I (page 210). It lives in the stagnant water of ponds and brooks and pools.

If we were making up a set of scientific riddles, Amœba might be the answer to a number of them. For instance, what is it that has neither legs nor wings, and yet moves? Amœba. Its method of locomotion can best be described by saying it streams along. Any part of it can go first. It can push out any side of its fluid body and then stream along in that direction. What is it that has no muscles yet can contract and expand? And what is it that has no mouth and no stomach and yet eats? Amœba. Any part of its body touching another microscopic body, flows around it, encloses it, and takes it into itself, retains what it wants of it, and then flows away from it. What is it that has no gills or lungs, but breathes? Amœba. It takes oxygen into any and all parts of its body, and gives off carbon dioxide, even as complicated plants and animals do. What is it that has no nerves yet feels? Amœba. It shows the effect of outside stimulation. Its movements can be changed, stopped, or started by a variety of stimuli. What is it that can divide itself in two and still live? Amœba. It has the wonderful property of all simple protozoan life of splitting in two, and thus becoming two individuals where there was only one before.

Here are all the life processes which are fundamental,—eating, breathing, moving, feeling, multiplying,—all performed by a drop of protoplasm to which life has given its magic touch. If this can be done with one drop of matter, it may well be that with a mass of cells life can work its familiar wonders of plants and animals.

IN OTHER WORDS

"The resistance of inert matter was the obstacle that had first to be overcome. Life seems to have succeeded in this by dint of humility, by making itself very small and very insinuating, bending to physical and chemical forces, consenting even to go a part of the way with them, like the switch that adopts for a while the direction of the rail it is endeavoring to leave. . . . Life had to enter thus into the habits of inert matter, in order to draw it little by little, magnetized, as it were, to another track. The animate forms that first appeared were therefore of extreme simplicity. They were probably tiny masses of scarcely differentiated protoplasm, outwardly resembling the amœba observable to-day, *but possessed of the tremendous internal push* that was to raise them even to the highest forms of life. That in virtue of this push the first organisms sought to grow as much as possible, seems likely. But organized matter has a limit of expansion that is very quickly reached; *beyond a certain point it divides instead of growing.*"—BERGSON.

IF BUTTERFLIES' EGGS WERE AS BIG AS BIRDS' EGGS

Photo by E. F. Bigelow

EGGSHELLS MAGNIFIED FOUR HUNDRED TIMES THEIR NATURAL SIZE

This whole group of shells was only three-eighths of an inch across. Yet see what a beautiful pattern each tiny caterpillar home had.

HOW LIFE BEGINS

In plants, in animals—from seeds, from eggs—from caterpillar to butterfly—from egg to chick.

WHEN we study life, we are studying the subject above all subjects in which people are most interested. So it is not surprising that we meet some of the most interesting people in the world, who have given of their time and strength and skill to find out and to present what we can read and understand in a few minutes. We must not make the mistake of thinking that because they present it so simply and we can take it so easily, it was as simple and easy for them to find it out. Dr. Longley went down with his diver's helmet every day for a summer, enduring many discomforts and exercising untold patience before he could get the pictures which he brought up for us. Mr. Finley spends days journeying to the remote spot where the birds he wishes to study live, and then many more days getting them accustomed to his presence so that they will go about their ordinary affairs before him without fright. Then a photograph shows us just what he saw at the triumphant moment when, in spite of the nearness of the camera and the man, the bird posed naturally within range of the lens of the camera.

So it is with these pictures of a different kind which are to show us in outline "How Life Begins" If we could do just what we would like best to do, we should show them to you in moving pictures, as Mr. Stone took them and has shown them in hundreds of war camps on both sides of the water and on many moving picture screens all over this country. Mr. George E. Stone planned, in collaboration with Prof. J. A. Long of the University of California, a set of moving pictures which should show from beginning to end the most fascinating story in the world, "the story of how new plants and animals come into existence." It was not any easy story to picture. Some of it must be photographed through a microscope, as it took place in too small quarters and with too small actors for unaided eyes to see it. Some of it took place in the water, some within shells or green pods, and some in the air. It took Mr. Stone and Dr. Long eighteen months to prepare their sets of films, but when they were done scientists everywhere rose up to praise them as both scientifically correct and fascinatingly interesting.

We cannot show you the moving pictures, for moving pictures cannot be put within the covers of a book. But we can do the next best thing. We can show you separate pictures taken here and there all through the films, and we can ask you to use your imaginations to picture for yourselves how these pictures might change on a screen from one into the next. When you are seeing in a tiny photograph little dots of living matter, we ask you to picture them not as little fixed dots but as wriggling specks of protoplasm. All pictures make us use our imaginations. Use them for these, and you will be able to think the changes which come from time to time. Then go out and watch them in the great moving picture which life spreads before you, the moving picture of Nature from which these pictures were taken. As you have read the story of how frogs' eggs develop into frogs and have met Little Frog at every stage of the change, so you can see in real life each of these changes which are here shown in outline before you. We took the moving picture films which Mr. Stone loaned for use in OUR WONDER WORLD and had an artist copy a few of them; and here they are, with the story as it is told in the titles for the pictures, somewhat edited and adapted to book form.

STORY AND PICTURE

"Life comes only from life. All new individuals arise only from other living creatures of their own kind. There are several methods by which new individuals arise. The simplest method is found in those animals and plants which consist of but one cell. Let us take some

From "How Life Begins," courtesy of Geo. E. Stone

A DROP OF WATER AND ITS LIVING ANIMAL CONTENTS

This set of pictures shows how the first animal life begins. A drop of water is placed on a slide and examined through a microscope. At once a swarming mass of life appears. These are protozoans, the simplest of all animals. These protozoans are then shown as magnified. The lettered diagrams explain the photographs which they follow. In the last picture appear two protozoans which have divided under our eyes from a single one above.

of these tiny animals. They are called protozoans. They live in stagnant water and can be seen only with a microscope."

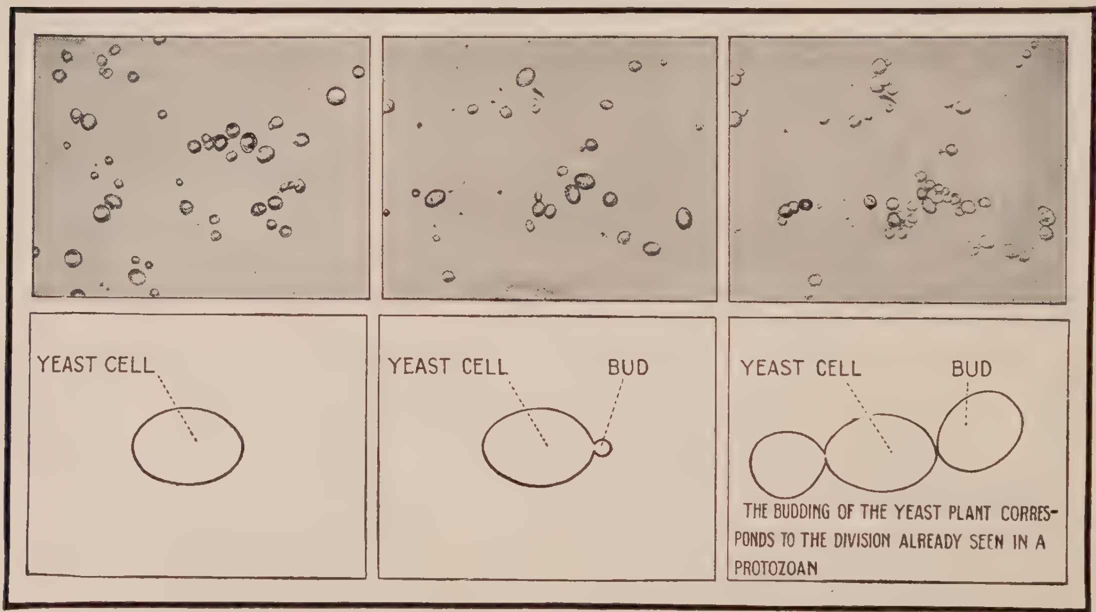
In the first picture you see the man with the microscope; next, reading from left to right, the protozoans, the little first creatures, as he sees them in the drop of water under the microscope. In the third picture we see four protozoans. The drawing (just below the man with the microscope) is a repetition in outline of the third picture. Look from one to the other and you will see that one is exactly like the other. "Three protozoans," it reads, "each consisting of a single cell full grown but not yet ready to divide." In the next picture they are beginning to divide. Watch the series through. The two look like a dumb-bell with a connecting rod, and then all at once there are two cells where there was only one in the picture at the head of the page. If you had been looking through that microscope, you would have seen just that happen. You would have seen a wriggling mass of protoplasm divide into two wriggling masses. It would have happened almost as fast as your eye can travel from one picture to the other. And not one mass of protoplasm only, but all the protozoans in the drop of water would be going through the same

process. They divide so rapidly that it is hard for even a mathematician to keep pace with them with his calculations. Certain protozoans at their normal rate of increase, if none were devoured or destroyed, might, it has been reckoned, fill the entire ocean in about a week. This, then, is the way life begins in its simplest forms,—one cell dividing into two, one tiny living animal dividing into two tiny living animals.

Plant life begins with the simplest plants in another but similar way. A pinch of yeast such as is used in making bread is taken and placed under a microscope. We see the yeast cells as they appear through the lens. Then in the next two pictures we can see, if we look carefully, the same thing happening that is shown in the diagram (much enlarged) below. "Each yeast cell buds off another like itself and thus new yeast plants come into existence. The budding of a yeast plant corresponds to the division already seen in a protozoan." Then on the screen is shown in ten seconds these changes that take place in ten hours.

"We have now seen," so the picture story runs, "how simple animals and plants produce others like themselves merely by dividing or by budding. These are the simplest methods by which new life can arise. Larger and more familiar plants produce others like themselves from cuttings or from seeds." The gardener takes a cutting from a geranium plant, puts it in earth in a pot, waters it, and watches it grow. With the development of a new plant in this way we are all familiar. We may start it any day by a cutting from a plant. But it is more slow than the protozoan or yeast process. It takes two months for the series of changes shown in our six pictures (page 106).

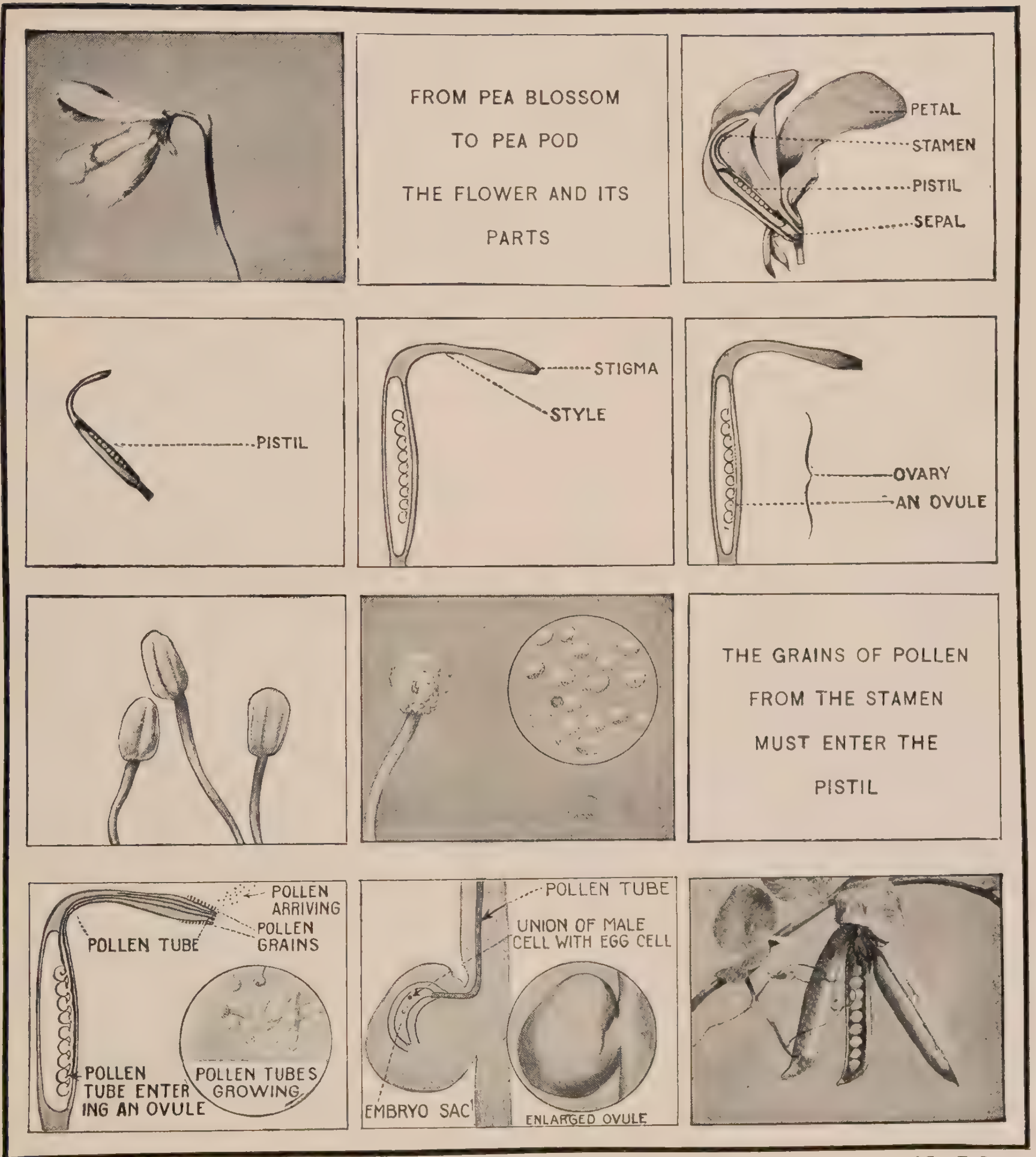
"Usually a plant comes from a seed. The seed originates in a flower on the parent plant. We shall now study the pea blossom to see how seeds originate." In the first picture is shown a pea blossom. The flower consists, as shown in the second picture, of several parts — petal, stamen, pistil, sepal. The pistil and the stamen are the only parts which are directly concerned in the formation of the seed. In the next three diagrams is shown the pistil, with its parts labeled—stigma, style, ovary, and ovule. In almost every plant there are found two kinds of cells, the female cells growing in the ovule within the pistil, the male cells in the pollen of



From "How Life Begins," courtesy of Geo. E. Stone

THE MICROSCOPIC YEAST PLANT — HOW IT BUDS

The simplest animal, the one-celled protozoan, divides itself into two, and thus passes on its life. The simplest plant, the one-celled yeast plant, used in bread making, reproduces by budding, as is shown in the pictures.



From "How Life Begins," courtesy of Geo. E. Stone

HOW SEEDS ARE FORMED IN THE PEA BLOSSOM

The higher forms of plant life grow from seeds or slips. The pictures and diagrams show how seeds grow in the familiar pea vine.

the stamen. The two must come together if there is to be a seed from which will grow a new plant. Next in the diagram is shown the stamen with its tip, or anther, which is filled with pollen grains. These grains burst forth from the anther and arrive at the stigma of the pistil. There they grow and form tubes, as shown in the diagram. The tubes travel along in the pistil until they enter an ovule. In the next diagram the male cell and the female or egg cell have come together, the ovule enlarges in its sac and becomes a pea. So all

the ovules develop into peas and the rest of the pistil becomes a pea pod.

In the pictures we have traced the beginning of life in the pea from blossom to pod. "We have seen how a plant and its flowers develop from a seed, also how a seed results from the union of an egg cell and a male cell. The egg cell came from the ovule and the male cell from a pollen grain. Just as peas originate in the flower, so do all kinds of fruits and seeds begin as parts of a flower." The moving picture goes on to show the sight with which we are all familiar, bees gathering nectar from flowers and helping to scatter pollen on the stigmas of blossoms.

Of the higher animals we take as examples the butterfly and the chick. "In all of these higher animals, as in the pea, the young animals develop from fertilized eggs." Here is Papilio, the swallowtail butterfly. (See page 107.) The caterpillar. The first meal of the caterpillar consists of the empty eggshell. After that, it feeds entirely on the delicate leaves of the anise. During the first ten days after hatching, the caterpillar sheds its skin three times. At the third 'molt' it loosens its black, hairy skin and emerges a beautiful green caterpillar marked with yellow and black. For another ten days the caterpillar is quite active and eats ravenously. Then it undergoes a profound change by which it becomes transformed into a butterfly." This change we see shown in the next six pictures. "First the caterpillar spins a silken loop by which it attaches itself to a firm support. Within a day or two its skin splits down the back and it wriggles out a chrysalis. The chrysalis may last several months during which it hangs motionless. At length the chrysalis shows signs of activity and

From "How Life Begins," courtesy of Geo. E. Stone

THE GROWTH OF A GERANIUM FROM A SLIP

Plants reproduce either from seeds, as in the pea, or from cuttings or slips. It took two months for the series of changes shown in these pictures.

female lays her eggs, already fertilized, upon the leaves of the sweet anise. When first laid the egg is creamy white. Ten days later the dark form of the embryo* may be seen through the membrane of the egg. Soon the embryo eats its way out of the egg and hatches as a tiny black at the end of two days suddenly splits down the front and out struggles a butterfly with crumpled wings. The newly emerged butterfly clings to a stalk while its wings expand. Three hours later, the wings are fully extended and the beautiful creature takes flight."

* Embryo means a young plant or animal in the early stages of development.

THE LIFE HISTORY OF A BUTTERFLY

From "How Life Begins," courtesy of Geo. E. Stone

AS LIFE IS PASSED FROM ONE GENERATION TO THE NEXT

It takes ten days or two weeks for the tiny black caterpillar of the first stage to emerge from the egg. During the first ten days after hatching it sheds its skin three times, appearing after the third molt a beautiful green caterpillar marked with yellow and black. For another ten days it is quite active. Then it goes into the chrysalis stage, which may last several months, coming out at last a beautiful butterfly.

So we see in picture the wonderful transformation from egg to caterpillar to butterfly, which is another chapter in the story of "How Life Begins." With the story of the frog, also shown in the moving picture, we are already familiar. We pass directly to the chick. "In the animals thus far studied, the young receive no care from the parents. In the examples to follow it will be observed that the mother cares for her offspring from the time that the egg begins to develop until the young can care for themselves. The eggs of the chick cannot develop unless they are kept warm. The warmth is provided by the mother hen, who sits on the eggs until they hatch. We are now to examine the egg to see how it gives rise to a chick. Before the egg can develop into a chick, a spermatozoön must unite with a part of the yolk. This fertilization takes place within the body of the hen, before the yolk is surrounded by the white and the shell. If the top is carefully removed the embryo may be seen lying on top of the yolk. The embryo is shown when thirty-six hours old, fifty-two hours old, seventy-two hours old, one hundred hours old. At this time a network of blood vessels has extended further over the yolk and carries nourishment to the embryo. In the next picture it is nine days old; then, twenty-one days old, when the egg hatches, and the chicken comes out of the shell."

The picture story goes on from the chick to the rat with its baby rats, the mother cat with her kittens playing about her as the chicks were about the mother hen, and ends with a beautiful baby in the arms of a lovely mother. So life begins. The interesting story of the care which the higher animals give to their young is a chapter by itself.

IN OTHER WORDS

"The higher we get in the scale of creatures, the longer the period of infancy, and the more the care displayed by the parents for their young." — PYCRAFT.

"Perhaps the most fascinating phase of Nature is the way in which she cares for her children during the early part of their lives. The story of seeds and eggs has not been half told. Think of the tiny thistle-fluff which soars away, borne on the lightest breath of air; of the great coconuts in their husks, so hard that they will turn the edge of a knife; of the burs which ever patiently reach out for some passing creature to transport them to a distant home; of the cones of the forest, whose seeds may be transported by birds, or dropped to the ground only to smother in the shadow of the parent tree.

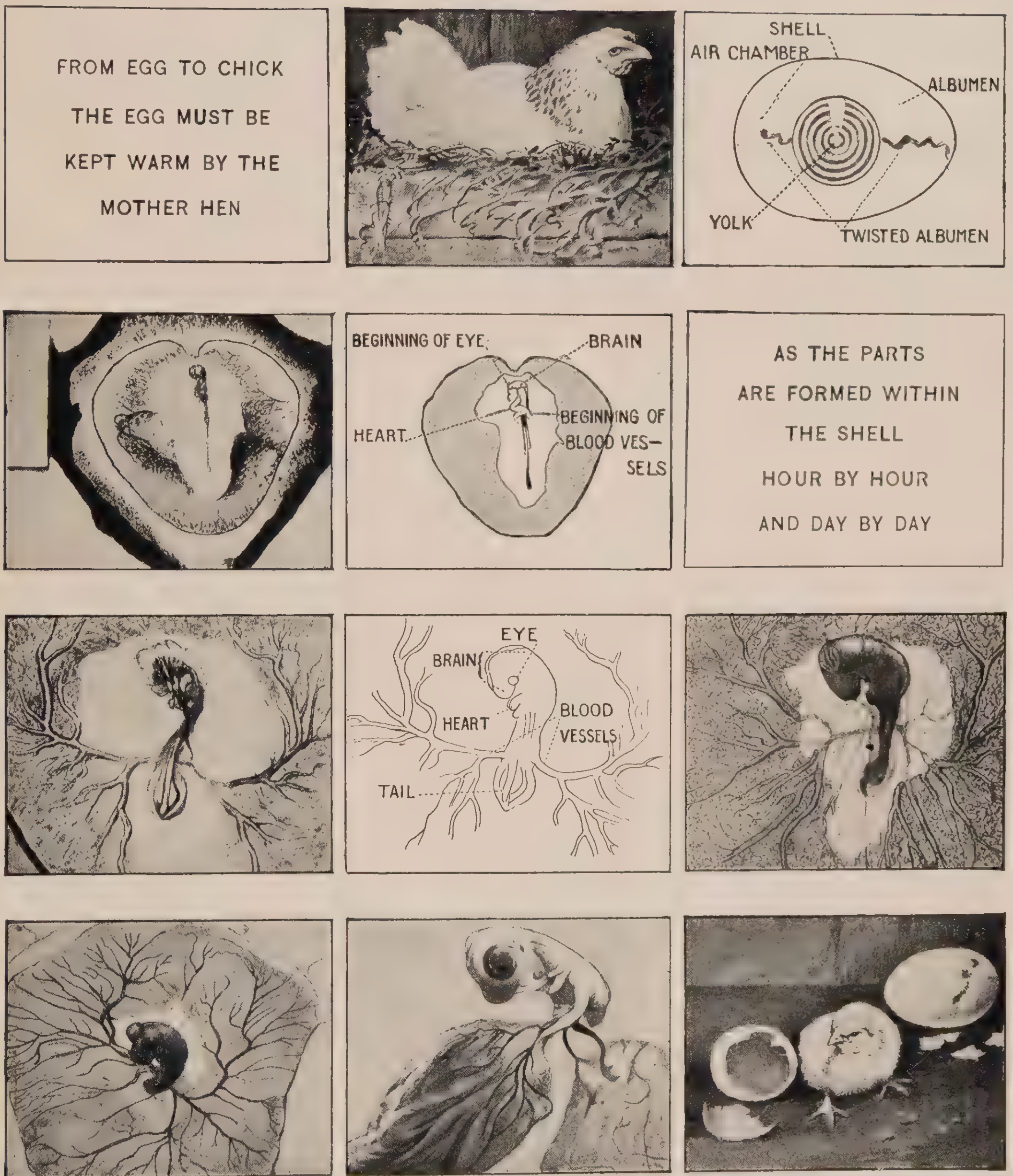
"In that 'mother of life' the sea, the wonder of first beginnings holds us spellbound. We see the tiny hydroids, those animal plants, flowering and budding on their waving stalks, and presently setting free their 'seeds' — jellyfish — throbbing with life, drifting away on the ocean currents. Again observe these jellies scattering behind them an untold host of eggs, as a rocket marks its path with a myriad of sparks. Think of the salmon seeking her spawning-grounds in the uppermost reaches of rivers, or of the cod boldly playing for her offspring the chance in the lottery of life in the open ocean. Of her nine millions of eggs, will one survive?

"How strange is the four-tendriled purse-like cradle of the baby shark; how delicate the forms and patterns of butterflies' eggs! and was there ever a more model parent than that frog which holds its eggs in its mouth until the tadpoles grow up? . . . Leading all in beauty and interest are the eggs of birds." — BEEBE.

Photo by R. W. Shufeldt

CALIFORNIA PARTRIDGE

WHAT HAPPENS WITHIN AN EGGSHELL



From "How Life Begins," courtesy of Geo. E. Stone

THE DEVELOPMENT OF THE CHICK

If the top of the shell is carefully removed, the embryo may be seen lying on top of the yolk. In the picture at the left of the third row, the embryo is thirty-six hours old; at the right of the same row, fifty-two hours old; in the fourth row, one hundred hours old, then nine days old — and at the end of twenty-one days the chick breaks the shell and comes out.

A WILLING PRISONER

A MOTHER BIRD WALLED IN FOR SAFETY

Hornbills of the tropics find a convenient hollow in a tall tree and clear it for a nest. The female hornbill enters and builds from within an imprisoning wall of plaster, the male bird helping on the outside. Only a small window is left through which the devoted husband feeds her till the eggs are hatched and the young birds have passed the helpless stage of infancy. (See page 116.)

Photo by Wm. L. Finley

WHITE PELICANS

IN NATURE'S NURSERIES

The wonder of life, as seen in a conger eel that lays fifteen million eggs, a fly that boards out its babies, plants that run hotels, a caterpillar with a nursery on his back, a beetle baby that must catch a ride on a bee, a father frog that carries eggs in his mouth — in fish that travel long distances to spawn — in a bird that lays only one egg and lays that on a rock — in nests that float on water — in a mother bird imprisoned in a tree — in a kangaroo that carries her baby in a pocket — in an opossum that swings her babies up on her back — in four-footed creatures that build nests — in a nest that is built of air.

EACH year a tide of life sweeps over the world. From the life that has come to maturity there comes new life in abundant measure. For this young life there must be careful provision. This provision Nature makes in a variety of interesting ways. For the higher animals there are separate nurseries for each family. Father or mother or both watch over and care for eggs and young until they come to an age and size to fend for themselves. The lower creatures need no such care. Their eggs, like the seeds, develop in Nature's big nursery and come to a quick maturity. Nature's nursery is coöperative. Not only do wind and sunshine and rain perform for it their good offices, but other living things are made unconscious caretakers and providers for new life of a species utterly different from themselves. Nature sees to it that there is sufficient provision of food and warmth and care to bring to maturity a number of each species adequate to ensure its own continuance. This is Nature's business, if life is to continue, and we shall see with what ingenuity it is managed.

THE WIDE WORLD AS A NURSERY

The tiny central life seeds of the plant are surrounded, as we have seen, by a supply of food which will suffice them until they can reach down into the earth and up into the air for nourishment. Often these seeds are wrapped, as is the chestnut, in a prickly bur for protection until they have come to a suitable size for independent life. The frog's eggs, cast upon the water, float in a jelly upon which the young feed

as they emerge. This is the extreme of independence and self-nurture. There is no parental care. The seeds may be dropped anywhere. The eggs of fishes are scattered by the thousand. Where so little care is exercised, there is enormous waste. Of the thousands of eggs of fishes only a very small proportion come to maturity. "The conger-eel lays, it is said, fifteen million eggs. If each egg grew up to maturity and reproduced itself in the same way, in less than ten years the sea would be solidly full of conger-eels." Again, "an annual plant producing two seeds a year only would have 1,048,576 descendants at the end of twenty-one years if each seed sprouted and matured."

This is doing business on a huge scale, with much waste, the only way of balancing being to keep the net increase safely above the net loss. It is a system of taking the world as a nursery and throwing out life into it with what appears a reckless extravagance. Its justification is in the food value of the young life thus thrown out. The plants and creatures that never approach maturity have served their purpose as food supply for the comparatively few which do survive the struggle for existence.

BOARDING OUT BABIES

As life rises higher in the scale, there is a change in the method. Long before the parents come to conscious care of their young, they are endowed with a marvelous instinct by means of which they make most minute and perfect provision for the babies which they will never see. The gallfly selects a plant which will have suitable food for its young. It pierces the stem or leaf, lays its egg, and goes away. Its part is done. The tiny larva, when born, begins to suck away the lifeblood of the plant. In self-defense the plant sets to work to build a room and store it with food. The results are the galls

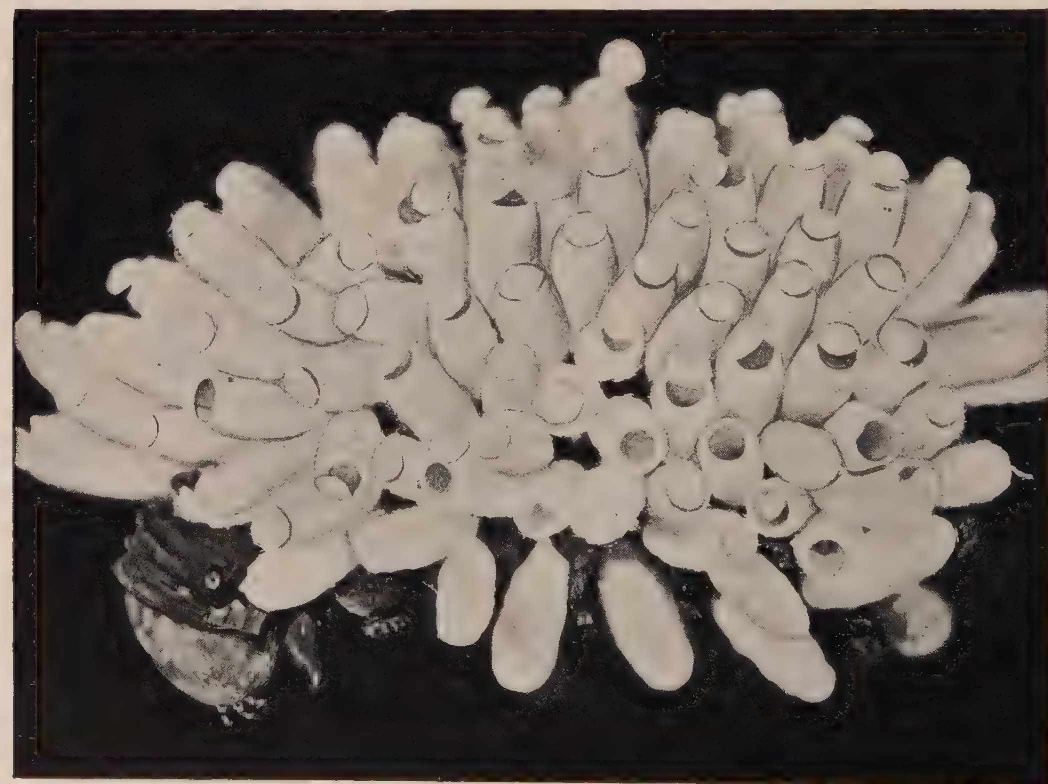


Photo by E. F. Bigelow

AN UNWILLING VICTIM

This caterpillar (the larva of the hawk moth) has been pressed into service as a moving nursery. A parasite has laid its eggs on the caterpillar's back. Each cocoon has a lid which will open to let the occupant pop out like a jack-in-the-box.

A PLANT THAT RUNS A HOTEL

Photos by E. F. Bigelow

PLANTS FORCED TO CRADLE AND BOARD INSECT BABIES

These balls are not the natural fruits of the plants on which they grow. They are galls, rooms stored with food, which the rose, the hackberry, the oak, and the goldenrod were forced to build for the young of tiny insects, gallflies. The oak gall (in the lower left-hand corner) is cut open to show the insects.

which appear on rosebushes, oak trees, and many other plants and trees. They look like an odd fruit of the plant. But cut one open and you will find (as in the picture on the previous page) a host of insect babies comfortably quartered within. These plants have been forced in self-preservation to build nurseries in which these insect babies are to be cradled and boarded.

The unhappy caterpillar of our picture has been pressed into most unwilling service by some parasite, which laid its eggs on the caterpillar's back. They have grown little cases in which to mature, each box with a tiny lid, so that the young can at the proper moment emerge like a jack-in-the-box. Meanwhile they are probably feeding on the lifeblood of the caterpillar. It is doubtful if he will survive the strain of his load; his task in furnishing a moving nursery will probably keep him from fulfilling his own destiny and coming out later as a hawk moth.

DO THEY KNOW?

The marvel in each of these cases is how the creatures know where to lay their eggs. What instinct guides them to choose the right spot where their young will have the needed food supply? Out of a garden of plants what unerring instinct sends them to the right one? How does the larva of the oil beetle, which has never come in contact with a bee, know enough to cling to the bee which comes to visit its flower? This active little larva comes out from the egg, wingless but with the power to run about and climb and with the instinct to cling to a hairy body. It climbs into flowers, and when a bee comes to visit the flower in search of nectar, it seizes hold of his body. The bee carries it to the honeycomb. When the bee lays an egg in a cell, the larva climbs on the egg and floats in the honey. It eats the egg, it molts, it then eats the honey, and so is fed until it comes to maturity. Think of a tiny larva living on the ground which must find a honey cell in which to grow; think of its managing to get up into a flower, and then catching a ride on a bee! It would seem to us one chance in a thousand for rearing a family. Yet it works. And hundreds of similar plans, which would seem to us so improbable as to be hardly worth trying, prove their efficiency by the test of success. Every larva does not find a bee, but a sufficient number are carried to the honey-cell nurseries to perpetuate their kind.

The first sign of development in parental interest is in those lower animals which, like the Surinam toad, carry their eggs with them. She did not drop her eggs into the water, but got them tucked away in pockets on her back. Another member of the frog family — a father frog, at that — carries them in pouches on either side of the mouth, so that, as in the old fairy story of "Diamonds and Toads," little frogs literally jump out of his mouth into the world. The curious little upright sea horse carries eggs about with him.

THE GREAT SPRING DRIVE

Many animals are very particular as to the spot where they will lay their eggs. The robber crabs make long journeys, as you will remember, back to the water of their birth to spawn there. The great fish migrations and most of the bird migrations are connected with the custom of breeding in a certain region. The salmon move shoreward to spawn in our Pacific Coast rivers. Birds travel thousands of miles to build their nests and rear their young in the accustomed and suitable spots. There is nothing in the world more fascinating than the great spring drive of all Nature to set up its nurseries and go to the task of rearing families. A whole book could be written, full of interesting and widely differing stories of the wonderful and beautiful response of all creation to this inner call. We can only run over quickly some few typical examples

BIRDS AND THEIR EGGS

No nursery is more familiar nor more fascinating to us than the nest of a bird. We rejoice in the return of the mating birds as a sign of spring and approaching summer. We watch the setting up of housekeeping of these tiny neighbors of ours as one of the precious incidents of the year. Birds' nests illustrate the extreme of care and protection of young as it is exhibited in animal life. Birds start with so little, — no hands, no tools but their beaks, — and swing out from the high branches these marvelous

cradle-homes. Yet even among birds there is wide variation in the amount of care expended or of effort necessary. The sea birds which breed on remote and inaccessible rocks do not expend time or effort on nest building, nor do they lay many eggs. Penguins, gannets, murres, puffins, auks, petrels, guillemots, and other birds of cliff regions near the sea, have the habit of laying only one egg, and this one egg in an exposed situation. The custom justifies itself, for harm rarely comes to the young, and the line is perpetuated. In the picture is seen the single egg of the pigeon guillemot. The bird makes no nest, but lays its egg on the bare rock. Turn back to Dallas Lore Sharp's description of his visit to the coast of Oregon where these birds live, and see the photograph of him as he creeps up among the eggs to the mother bird. (Volume III, page 139.)

The turkey buzzard is one of a group of birds that have the beginnings of a nest, — a heap of straw or reeds, scraped together in a cove. The gull makes a nest of dry weeds; its eggs are, as you see, protectively colored. It is part of the big scheme of Nature, as we have seen, thus to throw the mantle of invisibility around its children. The grebe's nest shown in the picture exhibits careful structure. It is a floating platform made of dead reeds, hollowed in the center for the eggs. Red-tailed hawks make for their nest what looks like a hastily thrown together pile of sticks. We shall talk later of the marvels of bird architecture. From the point of view of provision for and care of their eggs, it is evident that birds give the eggs the care they need. In many cases elaborate nests are the result; in others, especially where there are only one or two eggs, parental

Photos by Wm. L. Finley

A SERIES OF NESTS

The single egg of the pigeon guillemot (top, left) is laid in a convenient hollow on the bare rock: the turkey buzzard make a rough nest on the floor of a cave (top, right); a nest of dry weeds is prepared for the eggs of the sea gull; the grebe builds a floating platform of dead reeds.

Photo by Wm. L. Finley

YOUNG RED-TAILED HAWKS IN NEST

care seems to suffice without a carefully built nursery.

The murre, for instance, does not desert her single egg. She "broods her egg by standing straight up over it, her short legs, by dint of stretching, allowing her to straddle the big egg, her short tail propping her securely from behind." The emperor and king penguins give most devoted care to their single eggs, which they lay on the bare ground, "often in extremely inclement weather when there are heavy storms of snow and severe frost. Each egg is brooded on the flat feet of the bird, and a warm flap of skin and feathers, specially enlarged during the breeding season, hangs down and covers it like a blanket. From time to time the male and female relieve one another, and this is done with a quaint ceremony of bowing, and with a careful scrutiny of the egg before it is handed over."

Hornbills, birds which live in Africa, Australia, and other southern lands, have most peculiar nesting habits. A hollow is cleared in a tall tree, and the bottom of the nest is covered with dust and chips. Into this hollow, when nesting-time comes, the female bird goes and sets to work to shut the door on herself. In this undertaking the male bird helps from the outside, and together they build a solid wall, he using his big beak as a trowel to plaster up the opening with clay in such a way that she is literally walled in, with only a small hole left for a window. Through this window the father feeds her during the time of her brooding over the eggs and after the helpless baby hornbills are hatched. It is hard, constant work for him, and after three weeks of it he is worn thin. When the young are safely hatched, father and mother tear away the plastered wall and together carry on the guarding of the nest and feeding of the young.

A LONG CHILDHOOD OR A SHORT

"After the labor of feeding," writes Thomson, "comes the fine art of education." The duration of childhood of living creatures varies greatly. The butterfly has, in a sense, no childhood, certainly no parental care. At each stage as it emerges, first as caterpillar, then as butterfly, it is able to take complete care of itself. Little Frog must feed himself from the moment he emerges as tadpole or frog. But in the higher animals the young come into the world unprepared as yet to meet its requirements. For them there must be, for a longer or shorter period, parental care.

The human baby has the longest childhood of any living being. Birds must rear their young and train them to independence in the brief summer months before the change of season drives them either to migration or to winter habits. There is nothing more charming to watch than the education of a little family, whether of birds or kittens or puppies or ducklings, into the ways of the world. A giraffe, it is said, is able to stand up in about twenty minutes after its birth, to run freely in a day or two, and to nibble grass in three weeks. Young camels are active and playful, and can move about at once. Baby elephants can move and follow the mother almost at once. "The mother is devoted, incessantly stroking the young with her trunk, and defending it rather savagely from

Photo by Wm. L. and Irene Finley

AN OSTRICH EGG, AND A CHICK TWO DAYS OLD

This baby ostrich is only two days out of the shell; yet see its size compared to the egg by which it stands. The ostrich has a short childhood and is ready before many hours or days after birth to take care of itself. (Facts concerning length of childhood are from P. Chalmers Mitchell's "The Childhood of Animals.")

Photo by Wm. L. Finley

BRANDT'S CORMORANT, BESIDE NEST AND YOUNG

any rash intruder. . . . It does not use its trunk for drinking or even for picking up food for some weeks. The calf remains with the mother for several years until it is very well grown."

Young beavers are born naked and blind and spend six weeks in the special chambers in the beaver dam which have been prepared for them. Then they begin to follow the mother out into the world, "but remain under her superintendence for two years, after which they pair and set up in life for themselves. The intelligence of beavers is much higher than that of other rodents, and the long period of youth, under the tutelage of the mother, is occupied in learning not only what is necessary to the individual, but the art of living with other beavers in a well-disciplined community, doing work for the common good."

The kangaroo mother carries her baby with her in a deep pocket in her furry coat. For a period varying from a week to several weeks it lies motionless in the pouch, then it begins to push its head out and take its first look at the world. "Soon after its first appearance it begins to nibble, and as the mother stoops down to crop grass or hay, the head of the youngster is thrust out and it also begins to pick at food. Gradually it learns to push out its head more and more, and even its forepaws, but as soon as the mother is startled and sits up to look toward the source of danger, the young one retreats into the pouch, leaving only its head with bright twinkling eyes visible. Still later on the young one occasionally comes out of the pouch altogether, and feeds on its own account, hopping near the mother. At the first sign of danger, however, the mother stoops down, opens the pouch widely, and the young one bolts into it head first, and then wriggles round until it has reached its favorite position with only the head protruding."

The opossum carries her young on her back, each little opossum twisting its tail around the long, strong tail of the mother. A mother opossum with her load of children peering over her back is a fascinating sight.

FOUR-FOOTED NEST BUILDERS

Nest building is so characteristic of birds that we are likely to forget that this type of nursery is not their exclusive, patented model. The

Photo by Wm. L. and Irene Finley

FEEDING COYOTE PUP FROM BOTTLE

Shufeldt after W. Reid

TASMANIAN KANGAROO WITH BABY IN POCKET

little harvest mouse swings high in the cornfield a charming nest, pictured in the center of the color plate facing page 266. It "weaves a nest which can be compared only with some of the most elaborate habitations constructed by birds." Gilbert White of Selborne thus described it years ago: "One of these nests I procured this autumn, most artificially platted, and composed of blades of wheat; perfectly round, and about the size of a cricket ball; with the aperture so ingeniously closed, that there was no discovering to what part it belonged. It was so compact and well filled that it would roll across the table without being discomposed, though it contained eight little mice that were naked and blind." Dormice, water voles, and other rodents build nests, the most familiar being the squirrel's nest of leaves, moss, and fibers, carefully interlaced and set in the fork of a tree or in a hole in the trunk or branches. The nests of the orang-utan, the great ape of Sumatra and Borneo, are platforms built high in the forest trees. They are used as nurseries, but are also sleeping places for the adult apes.

FISH THAT BUILD NESTS

Here we have a real step forward in Fish World. Not content to abandon their eggs to the wide waste of water, or even to leave them in unprepared though fairly suitable spots, some fishes actually build nest nurseries.

One of the simplest nests constructed for young is that made by the sunfish. This is merely a saucerlike excavation in the sand. In diameter it is about twice the length of the fish. It is made by violent jerks of the caudal fin, by which means many of the larger pebbles

are driven to the circumference of the circle. Some pebbles the fish also carries in his mouth. The bullhead, a catfish, makes a similar nest.

Lampreys make a circular depression two or three feet wide in the river bed. The same sucking disk around the mouth which acts like a vacuum sucker, making it possible for them to cling to rocks, enables them to carry rocks out of the chosen section until a shallow basin is formed. Lampreys are shown in our photograph working on their nest. Sometimes several couples combine in making and then in using the nest. This is hard work. It takes a great deal of energy for even a good-sized lamprey to uproot the firmly fixed stones and carry them off. Often they are bruised and their skin is worn before the nest is completed. Young lampreys have a larva existence (as young frogs have a tadpole larva existence) of three or four years before they develop into true lampreys and make their way down the river to the sea or the lake. They spend a full month in the nest, then make burrows in the sand or mud. It is curious that lampreys should go through this laborious process for they are a very low order of fish, with extremely low mentality, betraying uncommon stupidity sometimes even while engaged in this process of nest making.

Bowfins make the real little weed nests shown in the photograph, which might easily be mistaken for the nests of birds. The stickleback also builds a nest among seaweeds, a nest with an entrance, an exit, and a little enclosure in the center. In the case of both bowfin and stickleback the father is the caretaker in this setting up of a nursery. It is he who usually builds the nest, entices his mate thither to lay her eggs after which she returns, unconcerned, to her ordinary pursuits. Not so the father. He stays and guards the nest, driving off all dangerous visitors, and seems even to tend the young fish when they hatch, acting as protector and guardian for their first trips into the watery world around them.

A NEST OF AIR

To build a nest out of air sounds like a fairy tale; yet that is what the Chinese paradise fish does. You will remember how the water spider

Courtesy of American Museum of Natural History

SEA LAMPREYS BUILDING THEIR NEST IN RIVER BOTTOM

Lampreys carry off rocks from the spot chosen for their nest, leaving a shallow basin. Often a nest is coöperative. It is no easy matter to uproot a firmly fixed stone and carry it off with only a sucking disk for a tool.

Courtesy of American Museum of Natural History

A BOWFIN BUILDING A NEST

The bowfin and the stickleback, among fishes, build nests of stalks and weeds which might easily pass for the nest of a bird.

carried down on his hairy back bubbles of air and held them confined in an inverted diving-bell home spun of silk, thus securing for his babies a dry home in the midst of a world of water. The paradise fish rises to the surface of the water, sucks in a big mouthful of air, and slips under water again. Then he lets it escape, and it rises to the surface of the water and floats there in the form of a bubble. This process he repeats, until a second, third, fourth bubble has been floated. Nor does he stop with a small number. Sometimes there are hundreds of bubbles clinging together in a mass three or four inches wide. These bubbles do not burst, for each one while it was in his mouth received enough of a coating of slime or mucus to hold it firm and make them stick together. They are really little air sacs, fastened together by their own stickiness, forming a floating air raft. When the nest is done, the little paradise fish goes forth and seeks a wife, bringing her to it. She lays her eggs beneath it, and they are so very buoyant that they do not sink but float upward and stick to the under side of the raft. It is said that the raft builder hovers excitedly about while the eggs are being laid, watching that none float away, or if they do escape, swimming after them and bringing them back in his mouth, as a dog brings back a ball. Then he mounts guard over the eggs, while the mother fish swims uninterestedly away. He moves the eggs about; he keeps the tiny fish under the air raft when they hatch; and does not depart till they can swim freely and the nest has served its whole purpose.

Into the story of underground burrows, of lairs in the forest, and of caves on the mountain-side, the homes of animal babies, we have not space to enter. They are more familiar to us from our own observation and general reading than these less easily observed shelters. From the few more or less conspicuous instances which we have gathered here, we shall all be convinced anew of the infinite pains, variety, and skill with which Nature each year sets up her nurseries.

From Shufeldt

HIPPOPOTAMUS IN HIS NATIVE HAUNTS

SUITS FOR ALL STYLES AND SEASONS

The inventiveness of life, as seen in hair coats, in skin coats, in fur coats, in feather coats, in waterproof coats, in new coats each season.

MAN is the only member of Nature's great family who clothes himself. For all the rest of the living creation Nature makes the garments. She provides for man a soft, flexible double layer of skin which keeps from injury the precious mass of nerves, veins, blood vessels, and vital organs within; but to carry on the adventure of life outside a very narrow hot belt on the earth's surface he must supplement this natural covering by borrowing from the plants and animals materials out of which to fashion his clothing. Spending so much time and effort in providing his own wardrobe, he can better appreciate the suits turned out in Nature's workshop. He makes for himself a kind of leather, but he cannot rival Nature's leather, which is soft, durable, self-renewing, and, during the period of its wearer's growth, self-expanding. He makes hairy textures but he cannot equal Nature's fur. In each branch of the costume business,—hair, fur, feathers, and scales,—Nature is past mistress.

FROM SKIN TO HAIR

As usual Nature's system is very simple. She works out her whole amazing show of spring, summer, and all-the-year-round suits on the simple basal plan of an inner skin which is very much alive and an outer skin, less alive but capable of a variety of developments. From this outer skin come the hair of man's head, his finger and toe nails, as well as the smooth surface which protects the inner skin from many a

prick and bruise. From it come the feathers of birds, the fur of animals, and all the other variety of Nature coverings.

The hippopotamus, living in the tropics, needs no elaborate coat of hair to keep him warm, but there are stinging and biting insects which will settle in clouds on his body and thorny plants between which he must push his way. If his outer skin were as thin and tender as man's, he would not only suffer, he would perish. But look at the skin that hangs in folds at his neck and stretches firmly over his huge body; it is an inch or an inch and a half thick. It will take even a fierce tropical insect a good long time to work through that tough hide so that the hippopotamus will even feel it.

The bison, one of the big creatures of the earth, has another kind of life to live, that of an inhabitant of our North American temperate zone. His shaggy coat enables him to withstand the cold and storms of winter. Yet it is not too warm for comfort under moderate temperature conditions. While you are thinking of skin and hairy coats, open your "Nature Book," Volume III, at page 143, and run quickly through the pictures there. See the Siberian Mammoth of prehistoric days with his long hair. In those early days Nature seems to have tried out a wide range of experiments in coverings, from the naked creatures of page 152 to the heavily armored monsters of the opposite page. Beginning again at page 185, see the tropical tapir and the rhinoceros, with his thick folds of skin, and contrast him with the mountain goat, page 196. All through this section of Volume III you will find pictures which will illustrate for you better than words can do it the gradations from naked skin to heavy fur.

WHY IS HAIR A GOOD COVERING?

For most four-footed creatures of the earth hair has proved the ideal covering. There are a good many reasons for this. We all know how

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AMERICAN BISON, WITH SHAGGY COAT FOR WARMTH

hair grows. From the outer skin comes a mass of soft hairs, too many to count, growing close together, each with a root reaching far down through the outer skin, or epidermis, into or through the living skin below. (Epidermis is from the Greek, and means "over skin.") Only the lower part of the root lives and grows, pushing out by its growth the part already grown. How many thousand cells there are in a short length of hair, and how fast they are being

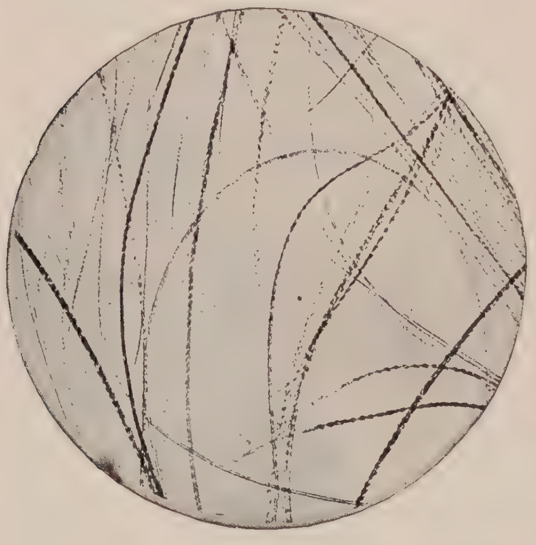


Photo by Philip O. Gravelle
HAIR OF BAT
(Magnified 100 Diameters)

renewed as it grows, Dr. Keen has told us in an earlier chapter. Down in the inner skin, the dermis, are the oil-glands which keep the skin and hair soft. The base of each little hair is open to them. From the way it grows, come the chief advantages of hair as a covering. In the first place, the hairs are close together; so they make an even, unbroken covering. Then, the outer ends can be worn off or can break off, and there will still be the protected root constantly renewing the hair. The oil supplied to this root keeps the hair soft and flexible. The smallness of each hair and its flexibility prevent its hindering quick movement. The smoothness of the hairs makes them shed water, and their closeness makes them confine air in small spaces, forming a sort of network or screen to hold air and thus by an air blanket keep the body warm by holding in its natural heat. Some one also adds the point that the many single hairs are easy to keep clean.

MANY STYLES OF HAIR COAT

Hair coats are plainly an excellent costume, warm, fairly waterproof, self-renewing, soft, and easily cleaned. But of hair coats there are almost as many styles as there are kinds of animals to wear them. Some animals wear short hair coats; some long, some straight, some curly. Even the hairs themselves are different. The microscope shows how the hair of a bat differs from the hair of a mouse, and both differ from human hair pictured on page 12. When the hairs are very fine and close together, the coat is named "fur"; when they are fine and kinky, giving them a tendency to mat together, as on the sheep, the coat is named "wool." The beaver wears two coats, an outer one of long, coarse hair, strong and smooth to shed water, a sort of overcoat beneath which there is the undercoat

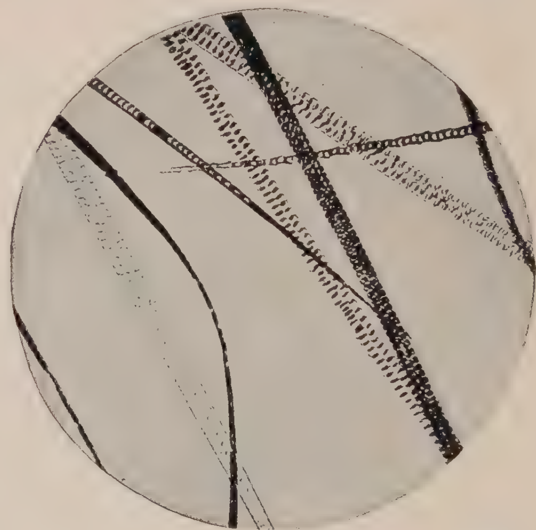


Photo by Philip O. Gravelle
HAIR OF MOUSE
(Magnified 100 Diameters)

of fine, soft fur from which beaver hats and neckpieces are made.

Usually the hairs of fur lie all the same way and can only be brushed that way; to try to lay them in the other direction is to "rub fur

the wrong way." The little mole who spends his time in underground passages which are often very tight for him is fitted with a fur coat which may be brushed either way. He can go backward or forward without the unpleasant experience of unduly roughing his fur.

For protection of its wearer hair often grows out into stiff spines, as in the hedgehog, or bristles, as in the porcupine. This is a method of self-defense, an adaptation for more than the mere covering for comfortable living, even as the armor of animals is a special adaptation. Just now we are thinking of Nature as costumer rather than as manufacturer of weapons or armor.

WATER ANIMALS THAT DO NOT GET WET

To live in water and not get wet would seem an impossibility. It would be if Nature did not provide waterproof coats. These coats are not of rubber, like our rain coats. Nature depends on a hairy coat to keep the inner skin dry. It would probably surprise you to find how little water penetrates the hairy coat of many of the water creatures like the beaver. In the water spider, which carries down air bubbles to its diving-bell home, the arrangement of hairs which catch and hold the air prevents water from working in to certain parts of the body. Water beetles of at least two species have fine hairy growths which protect them amazingly. It is not possible to explain simply and briefly how many of these animals actually live in the water without being wet, but the capillary action upon certain kinds of surface coverings does give to the creature a surprising protection.

From Shufeldt

THE DUCK-BILLED PLATYPUS OF AUSTRALIA AND TASMANIA

One of the strangest of animals, with a coat of soft dense brown fur, like an otter or muskrat, a duck's beak "jammed on its muzzle," webbed feet like a duck, a tail like a beaver. It looks like a very large, fat mole; it leads an aquatic life, making extensive burrows on the banks of rivers; and it lays eggs like a bird. It is a surviving link between reptiles and mammals.

HAIR AND FEATHERS FROM SCALES

It is hard to believe that the hair of a cat, the feather of an eagle, and the scales of a fish all

came from the same original model of skin covering. Yet such is the story that the scientists have carefully pieced together from the information at their disposal. And the original garment, which they believe to have been made first in Nature's workshop, before these other garments were designed, was the scaly covering of the fish. They tell how cold-blooded, slow-moving creatures wore scaly coats to protect them, coats like armor in their make-up of scale overlapping scale. Such scales, they bid us notice, are still worn by the armadillo. Cold-blooded snakes still keep the scaly covering. Fish do not go so far away from it. Then creatures became warm-blooded. As they developed speed and higher temperature, they needed coverings which would serve as a protection without impeding their movements. Some of them changed their fore limbs into wings and their scales into feathers. That feathers and scales are not so widely separated as they seem, we can see by comparing the photographs of the fish and the scaled partridge. But the resemblance runs much deeper into matters of shape and cell structure.

A SMOOTH, SLIPPERY COAT

As Mr. Brearley has well remarked, one need only try to catch or hold a fish in one's bare hands to realize that it is reasonably safe from capture by enemies which have no hook, net, or line. Fish scales are small, hard, rounding plates, overlapping each other in regular lines and patterns. Lying flat upon the body, they make a close covering which is perfect for life and movement in the water. They offer no resistance in swimming but cling to the boat-shaped body of the fish. From the skin beneath comes a sticky, slippery fluid which is an added protection. Both fish scales and feathers start in thickened groups of cells.

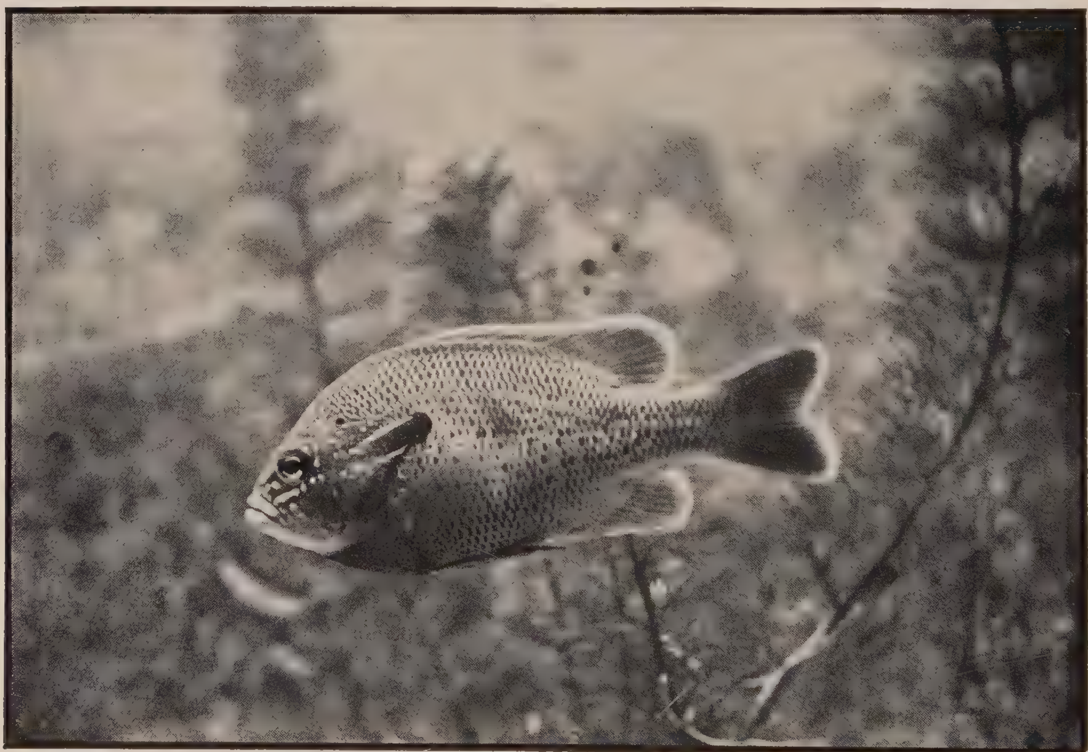


Photo by R. W. Shufeldt

LONG-EARED SUNFISH

Scales seem to have been a simple kind of covering from which both hair and feathers developed. Compare the scales of the sunfish with the feathers of the scaled partridge on the opposite page.

THE FIRST SUIT

Some creatures come into the world practically naked. They are usually of the species which have a fairly long and protected infancy, during which their parents care for them. Others are born with a warm coat of down feathers. Every one who has held in his hand a little chick knows the softness and fluffiness of his first suit. This is a suit which will soon be shed, being lifted clear of the skin as the next coat of true feathers pushes its way out, and so being, little by little, rubbed and brushed off. It is such a pretty baby coat that we almost wish it might be kept; but it must be shed, for it would not be a sufficient protection against wind and rain, heat and cold. Rather than regretting its speedy wearing out and off, let us be glad that so many birds, like ducks and chicks, have it and present themselves to the world thus attired. Those which do not — and among them are numbered many of our prettiest feathered friends — are queer, ungainly little creatures, unfeathered, or with the feathers rolled tightly in sheaths. Our photographs show young birds at all stages of their development. As the feathers dry and open, they stand out from the bird's body and often show the new warm undergarment of down which is growing at the same time and will serve for protection and warmth.

FEATHER COATS

Birds are the only creatures which have feather coats, and all birds have feathers. That is the one thing that is true of them alone. Even human beings do not borrow or manufacture feather coats; yet they are a very good kind of coat, for bird use, at least. Single feathers, whether of soft, downy plumage of the owl or the strong, firm feathers of the eagle, are flexible, elastic, light in weight, yet durable. Put together in overlapping layers, they make a coat which sheds moisture, holds in heat, offers no resistance to the air, and is no hindrance to movement. A single feather is a marvel past our understanding. A feather coat, wholly aside from its adaptation to use as wing covering for flight, is a garment unexcelled in Nature's workshop. Moreover, like many of Nature's garments, it is self-renewing. When a feather is full-grown it ceases to have a living connection with the inner skin and the system of blood circulation. So far as the life centers of the bird are concerned, it is from the moment of its maturity a dead thing. For this reason it may, when it becomes worn and frayed, drop off as the leaf drops from the tree, without in the slightest degree affecting the vitality of the bird.

Photo by R. W. Shufeldt

SCALED PARTRIDGE

The shape and style of these feathers make the scientist's story that feathers came from scales seem reasonable.

HOW A BIRD CHANGES HIS COAT

When a feather coat has become battered and worn through hard usage, it is cast off and a new coat grows out from that marvelous inner skin which is alive. This process is called molting, and it happens for birds always once a year, sometimes two or three times. Autumn is the time for the principal change. The hard work of the year is over; the nest has been built; the family hatched and reared; and the suits of the parents show for their labors. Then the feathers fall out gradually, and a new coat pushes

its way out from the skin. Nature does not provide this new autumn suit simply for good looks. Winter is coming. Migratory birds must soon start on their long journeys to the southland. Their wings must be in perfect condition for the long flight ahead of them. Other birds will stay in the cold northlands. Their coats must be warm for winter.

Photo by L. W. Brownell

THE FIRST SUIT

Young green herons in the soft fluffy covering which precedes the feather coat.

Again in the spring, when the birds are coming back to mate and rear families, many of them have a freshening of plumage, putting on often brilliant suits for the courting season. Male birds are especially likely to appear in the spring with gorgeous colors in wings and crest. In these gay costumes they will parade before the mates of their choice; by them possibly they may the more readily gain favor and consent.

Some birds, like the ptarmigan, take on a protective coat differing with the surroundings among which they spend the different seasons. For winter, there is a white coat which makes them almost invisible from a distance against the glistening snow. In the spring, this will be discarded for a brown and parti-colored garment, like the ground about them, with spots of white like patches of snow. This, too, will give place in the later season to a dark gray plumage, which will harmonize with the late summer and autumn colorings. Three uniforms a year is quite a record, but if it is necessary to safeguard life, Nature will issue them from its workshop.

THE WONDER OF A SINGLE FEATHER

A feather is one of the most wonderful structures which Nature builds. We have spoken of feather coats as if all feathers of each coat were alike, but the feathers on a single bird vary from flight feathers to the close body feathers, with many stages between, and the feathers collected from the members of the great bird kingdom would make a remarkable collection. Any one who knows birds can tell from a single feather or group of feathers many facts about the bird's habits, for certain feathers are especially adapted to flight of one kind, others to flight of another. The owl must move stealthily through the darkness. Stiff feathers would betray him by rustling in the air; soft downy plumage such as he wears makes his passage noiseless. The eagle flies high; his strong wing feathers can take the resistance of the air. The cassowary and the emu have given up flight; their feathers are more like coats of fine hair. Ostrich feathers would never be stiff enough for flight; yet how beautiful their waving plumes!

Some time you will have a chance to examine a feather under a powerful microscope. Even an ordinary reading glass will show you an intricacy of structure which you have not suspected by looking at a feather with the unaided eye. Each feather is made up of many tiny feathers. There are barbs and barbules and barbicels which fit into each other and interlock so that air cannot get through.

"Suppose we have a wing-feather from a common pigeon with a vane about six inches long," writes Mr. Beebe. "If we have patience enough to count the barbs on one side of the

quill, we will find there are about six hundred of them. So the vane of the entire feather has 1200 of these little side featherlets. One of these, from a narrow part of the vane, will show under the microscope about 275 pairs of barbules, which multiplied by the number of barbs on that side amounts to 330,000. Making a very low estimate of the whole vane, we have 990,000 separate barbules on this one feather."

Such is the complicated make-up of this one feather; yet Nature builds and renews them from the living skin as fast as they are needed. In similar fashion the snake grows a new skin when the one which he has worn all the year is worn out, and sheds the old one as one takes off and drops a cast-off garment. The hairy and furry creatures shed the old hairs gradually and renew them as they go about their daily business of living. To all creatures of any length of life comes in spring or fall or both this wonderful and interesting re-costuming to make them fit and fresh for the new season's demands.

Photos by L. W. Brownell

THREE YOUNG KINGFISHERS, AND AN ADULT KINGFISHER

The feathers of the three nestlings are gradually opening from their sheaths, while those of the adult bird are flattened and smoothly laid.

LIVING RAINBOWS

Life as artist — its color schemes, its patterns, and its shades — a butterfly's wing with ten thousand scales to the square inch — a blue feather that turns black when pounded with a hammer — Nature's use of paints, dyes, pigments, and mosaics.

COLOR is the royal bounty vouchsafed by Nature in its building up of a living world. It is the added touch, over and above the bare necessities as they might have been conceived, which makes for the joy of living. As children we have all recited the familiar verse which tells how "God might have made the earth bring forth enough for great and small" — but "without a flower at all." The thankfulness for flowers may be matched with a deeper thankfulness for color in the world.

To close one's eyes for a moment and try to imagine what it would be to live in the world of the blind, with color gone from one's consciousness, is to get a faint glimmering of understanding of what sunlight with its accompanying color effects contributes to life. Even with nightfall the world of out-of-doors is robbed of a thousand interests as its soft tints and brilliant hues merge into grays and blacks. The bird of paradise is hardly more conspicuous than the common crow when both are only dark shapes against a hazy background. Sunlight is responsible for color. To remind ourselves of how sunlight, split up and reflected, produces color, we need only turn back to our color page in Volume I, "Why We See Colors," facing page 100. But that tells only half the story. The bird looks black because it fails to reflect color rays, the frog green because it reflects only green. But why does the crow fail to reflect and the frog reflect only green? What is there about crow feathers or frog skin that will or will not reflect certain rays of light? Sunlight is the source of all colors, but the secret of choice lies with the frog, the crow, the green leaf, and the flower.

TWO WAYS THAT COLOR IS PRODUCED

One way to produce color is to put in coloring matter. As bluing is poured into water or dye is mixed and set, so coloring matter is deposited in the tissues of animals and plants. When we say "coloring matter" we do not forget that all color depends on light, that nothing has color in itself except as light falls on it and is held or reflected by it. But there are substances which wherever they occur give back certain colors. They are called pigments, from the Latin word for paint. Chlorophyll, the green coloring matter of plants, is a pigment or combination of pigments. Whenever it is present the cell in which it occurs looks green. When it disappears in the autumn, other pigments which have been overlaid by the chlorophyll show their presence by reflecting other rays from the sunlight.

To distribute paints or pigments in judicious proportions through the world would seem to us an obvious method of getting color effects. It is one of Nature's ways, but not its only way. The other is the rainbow way. When a rainbow appears in a broad arch across the sky, it is not the result of a sudden pouring of huge quantities of coloring matter into the air; it is an effect produced by certain conditions of the atmosphere. Moisture condensed in tiny drops of water has made a natural prism which catches and splits the white light of the sun and reflects it to our eyes in the broad band of spectrum colors. Sir Isaac Newton made his rainbow, as you and I can make one on any sunshiny day, by setting a glass prism in the light. The outer garments in which Nature has clothed its great family are made up of hundreds upon hundreds of natural prisms which catch and reflect sunlight. Many of them contain coloring matter as well as being natural reflectors. By a combination of simple reflection and pigment reflection Nature gets gorgeous color effects.

COLOR AND PATTERN

One of the joys of science is the way one fact fits into another. We have seen how life as it builds its living world does it upon the plan of

LIVING RAINBOWS

BIRDS OF PARADISE

No group of birds in the world can compare with the birds of paradise of the Malay Archipelago for marvelously developed and brilliantly colored plumage. In 1521 members of the Magellan expedition brought to Europe the first reports of these birds. Those shown in our picture are Wallace's standard wing (to the left), the King of Holland's bird of paradise (above), and the great bird of paradise (at the right), this gorgeous male bird with his long tail feathers and brilliant shading being one of the first species known to science. A picture can give only a hint of the beauty of these birds, for with the natural tints due to color in the cells they combine an iridescence and a metallic luster due to the structure of the feathers that make them in very truth living rainbows, reflecting brilliantly the sunlight as it falls upon them.

tiny cells, growing one upon another, one from another. As you have read the accounts of ten thousand cells in a square inch or in the twenty-fifth of an inch, or of other mysteries of structure as they are revealed by the strong eye of the microscope, it may have occurred to you to wonder what was the good of it all. Why all this minuteness of structure which no one could see? There are a good many reasons why the cell-by-cell system is a wise plan of building. We shall come upon them as we know more of living creatures, and especially of our own bodies. But if you think that until you looked through a microscope or saw photographs taken through a magnifier, this system of creature building never made itself felt to you, you are mistaken. As well say that piano music might have been made without the separate keys, so far as you were concerned. You did not see single cells; you cannot see single cells except as you examine them under the microscope. But those cells give the color and pattern of everything you look upon. If they were not there, if animals and plants were not built on this composite pattern, they would have an entirely different appearance to your eye. Color and pattern are the visible signs of a composite world. They are a by-product, so to speak, of a building scheme which fits together millions of tiny perfect pieces into one big whole.

Man sometimes makes pictures in a similar way. In churches and halls of the Old World and in some of our own fine buildings are pictures made by fitting together small bits of colored glass or stone into patterns. Stand near one of these pictures and you see only the individual pieces with dividing lines between. Stand off from them a little way, and you become so absorbed in the pattern of the whole that you lose the sense of the separate bits which make it up. All Nature's structures are built on the plan of these mosaics. But while the picture on the wall or in the pavement has had its separate pieces fitted together in a certain pattern for all time, Nature grows its mosaics and may change them as it wills. The feather coat of a bird may show vivid coloring in the spring, and then by a natural change of life take on a dull, protective harmony for summer and autumn. If it were all in one piece, the coat would have to be shed as we take off a garment, and a new one would have to be put on. By the life within the bird Nature can grow new cells which will give new patterns and colors to the feathers. The pattern and color of a young bird or animal is often entirely different from that of the covering which he will assume as he matures.

The interesting point is that color and pattern are not only due to growth; they are the

Photo by L. W. Brownell

YOUNG FLICKERS

signs of this cell-by-cell plan of growth. As the green of chlorophyll is Nature's trademark of leaf factories, so color and pattern in the world of life are the visible signs of that wonder world

of infinitesimal cells, set in many combinations, which lies in its details just beyond our unaided vision. We may not see each cell, but we can see the color schemes and the shadings and markings which they produce. Had it no other reason or purpose the cell system would have ample justification in the beauty which it produces.

REPEATING PATTERNS

With the tinted patterns on a butterfly's wings formed by color scales laid so closely that there are fifty to a hundred thousand to the square inch (as they are shown in our magnified picture), it might seem as if Nature would become confused and forget the model of arrangement for any single kind of creature. Nature does not forget. Its patterns run true. Our whole system of bird study, of butterfly identification, of fish and animal recognition, rests on the firm foundation of Nature's regularity. The wings of all members of a certain butterfly family will carry the same spots and stripes in the same relation to one another, so that he who has learned to name one will recognize its children and children's children. Scientists assign animals to their places in the scheme of life by more searching tests of structure than the color and pattern of their coats, but they are familiarly known and identified by these surface markings. Strip them of their coats and they would be not only difficult to recognize but unbeautiful to look upon. It is one of the foundation truths of the world that life tends always toward beauty. There are practical and utilitarian reasons for life's methods, but the mind in matter is always working through the useful toward the beautiful.

Photo by E. F. Bigelow

COLOR PATTERNS ON A BUTTERFLY'S WINGS
(Greatly Magnified)

The beautiful tinted pattern on a butterfly's wings is made by tiny scales, fifty to one hundred thousand to the square inch.

WHEN BIRDS AND ANIMALS ARE WHITE

White is almost always due to reflection. "When a piece of transparent glass or ice is powdered it becomes white like snow, and this appearance is due to the total reflection of the light from the mixture of little solid particles and intervening bubbles of air. The white of animal tissues is produced in this way. The fur and feathers of arctic mammals and birds, white patches on the skin and so forth, come about because there are little bubbles of air or of some other gas entangled in the structure of the tissue." In these air spaces the light is "reflected and deflected until, as in snow or foam, all color is lost and white results." White, at one end of the line, and iridescence, like that of a shell, or a certain metallic luster of a peacock's tail at the other extreme, are due to structure not pigment. Look at a humming bird under a microscope and its iridescent colors will disappear and only gray or black remain.

HOW BLUE IS ACCOUNTED FOR

No blue pigment appears, according to Mr. Beebe, in birds' feathers. If we were to take a parrot's feather in which much blue appeared and pound it with a hammer, the blue would disappear and the vane would become black. This he explains by the structure of the feather. The cells contain a brown or yellowish pigment, but between it and the sunlight lies a layer of many-sided cones or small projections which have little ridges along the sides. Acting as reflectors these change the yellow to blue. This is an example of the frequent system of obtaining color effects by a combination of structural and pigment reflection.

Photos by Wm. L. Finley

BARN OWLET, AND YOUNG TURKEY BUZZARD

Both in the soft white down coat of infancy.

WHEN NATURE PAINTS

Black, red, yellow, and brown are colors due to the presence of actual coloring matter. Usually they are so confined in the cells that they seem a part of the cell. But occasionally they come off at touch. "The brilliant crimson of the feathers of the touracos* is not only a pigment, but one that is soluble in soft water, and is washed out by a heavy shower of rain. A less well-known case is that of the black color of the Malay tapir. If the hand be rubbed over the dark portion of the body a black, greasy stain comes off, whilst the gray part of the body is devoid of this secretion."

As chlorophyll colors the leaves, so a red pigment, hemoglobin, colors the blood. These are probably the two most important pigments in Nature, for while the one makes possible the taking in of carbon dioxide (CO_2) from the air, the other, combining easily with oxygen and thus becoming an oxygen carrier, makes possible the distribution of oxygen throughout the body. The red of the blood gives the beautiful flesh tint which relieves the pallor of our bodies, while it is serving the excellent and necessary purpose of carrying the required oxygen along with it.

DOES NATURE KNOW, FORECAST, AND PLAN?

When a cloth-maker puts red dye into his vat, he does it because he wishes red cloth. He puts in the coloring matter in order to get the color. He does it consciously and with a definite purpose. Because human actions are governed by this type of conscious purpose, human beings will always ask the question whether Nature, working in color and pattern, creates its effects consciously with reference to their beauty or whether the beauty resulting is merely an accident. The truth probably lies between the two extremes. That there is mind in Nature we like to believe, and according to one of the leading schools of scientists we have every right to believe. The laws of Nature which used to be taken as a possible ground for arguing that there was no mind in Nature are now taken as an indication that there is a mind that works "through all and in all." How this mind works out in the growing intelligence of living creatures as they mount the scale of life, we shall see as we go further into our study. The question of color and pattern as we find it everywhere in the living world brings the matter up at a point very near its first calling itself to our attention.

Color and pattern are, as we have seen, the results of growth and plan of structure. Every visible thing must have color. Being in the sunlight it will necessarily catch or reject some kinds of rays. To that extent color is purely accidental, the result of happening to be in the sunlit world. But when it comes to the matter of the way the cells of a feather or the scales of a fish are arranged, or the pigments which appear in green leaves or red blood or the peacock's tail, color and pattern seem to have a double reason for being. The truth is Nature works with so wise and careful an economy that a process is at the same time useful in the business of living and contributory to the beauty of living. Nature does not create a substance simply as a pigment or dye. The substances which we class as pigments because they produce such beautiful colors, the physiologist classes as "by-products, waste-products, and reserve-products." By this he means that in the process of living, chemicals are thrown off and other chemicals are stored which give out certain color effects. We who look for beauty get the benefit of the beautiful color effects and color combinations which result. So when we come to the root of the matter we may safely say that Nature does not paint simply for the sake of painting, but attains the higher art of creating beauty while in the act of maintaining life. In the innermost recesses of the living world lie the causes of a scheme of coloring that will be to us the more beautiful as we know that it is the natural, beautiful effect of life.

IN OTHER WORDS

"The blues and greens of many birds and insects which do not change color according to the angle at which light is reflected from them, and the still more vivid metallic iridescent colors which change as they are moved about, and which are conspicuous in the eyes of the peacock's tail and in the bright tints of birds of paradise, are due to a combination of structure and pigment." — MITCHELL.

* Touraco, an African bird from one to two feet long.

A BLUE FEATHER WITH NO BLUE IN IT

COLOR BY DYES IN GROUSE'S FEATHER; COLOR BY PRISMS IN BLUE JAY'S FEATHER

If you held this blue feather to the light and looked through it, the blue would disappear. Hold the brown feather to the light; it stays brown. The brown feather has brown coloring matter in its cells; the blue color comes, as does the blue of the sky or the blue in a rainbow, simply from reflection. Its cells are tiny prisms. Pound a parrot's blue feather with a hammer; it turns black, for its prisms are destroyed. Pound a brown feather; it stays brown, for its chemicals remain.

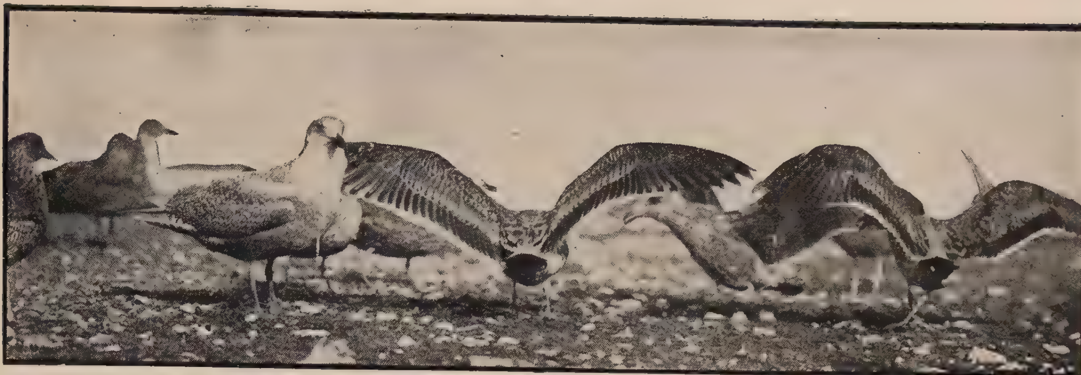


Photo by Wm. L. Finley

THE BUSINESS OF LIVING

The industry of life — how its creatures are always busy about their work.

ONE of the marvels of the living world is its activity. The "busy bee" is not unique in the energy and industry with which it goes about the daily round of life. Lazy creatures are the exception rather than the rule. The requirements of life, particularly those relating to food, force upon birds, beasts, fishes, and insects a steady activity which, in most cases, they readily undertake. The plants like robber dodder and mistletoe which shirk the business of food manufacture and steal their living are few compared to the vast army of plants which keep steadily at the task of filling their larders. The birds like the cuckoo and the cowbird which escape family cares by laying their eggs in other birds' nests are so exceptional as to be proverbial for their laziness. On the whole the world of lower creatures goes cheerily and energetically about its business of getting a living.

What a task it is that many of these creatures face! Not only must they feed themselves — and that is no slight matter when all the world is equally eager to feed itself — but many of them must, like the birds, build themselves new homes each year. As soon as these homes are built and the young have appeared, they must be fed, and growing young birds are as demanding in their appetites as growing children. All this activity must be carried on in the open, with the constant setbacks from wind and rain.

Only very wonderfully adapted animals could work so quietly, so uninterruptedly, and so successfully at such big tasks. Through the ages life has perfected its living machines. It has made beaks and bills and mouths and tongues which enable their possessors to search out, catch, and prepare food; it has given them tools with which to build their homes and safeguard their young; and it has given them weapons with which to defend themselves in the struggle for existence. Creatures are wonderfully well adapted to the varying lives which they live. We have seen how the animal that lives in a cold region has a furry coat to keep him warm. Even as animals are adapted in their bodies to the climate in which they live, so are they also adapted to the kinds of food which they will find and all the other conditions among which they are to keep themselves alive and comfortable and to bring up families. It is not easy for us to remember what a world of adaptive mechanisms lies just beyond our ordinary attention in the insect world. Vernon Kellogg has challenged us to remember that "if man were not the dominant animal in the world, insects would be," for they outnumber in kinds the members of all other groups.

It is always a pleasure to see how perfectly a creature's body fits its needs. Birds, beasts, and fishes, each in their own ways, find it a good world to live in. We, looking on, can find satisfaction in seeing how each fits its own world. We can add this feeling to our own personal pleasure in the world as a "fit" and happy world for ourselves.

THE CHAMELEON, WITH A TONGUE AS LONG AS HIS BODY

QUEER WAYS OF GETTING A LIVING

A bird that walks into a crocodile's mouth for its food — a fish that shoots — plants that set traps and catch insects — the biggest mouth in the world which eats the smallest kinds of food — fish that go a-fishing.

OF all the subjects upon which we come in our study of life, food getting is one of the most interesting because it has had such an effect not only upon the lives but upon the actual structure of the creatures of the world. "That the lower animals, at any rate, live to eat," writes Pycraft, "rather than eat to live, is made manifest by the often elaborate mechanism which has been devised to secure this all-important end." They must have food; therefore they must be fitted to get as well as to eat food, and so they are built as they are. While all food getting, even by the most familiar methods, has elements of interest, there are certain creatures which go about this business in ways that are unique and dramatic.

WALKING INTO A CROCODILE'S MOUTH

Writers customarily describe reckless bravery in the face of great danger by the phrases, "marching up to the cannon's mouth" or "walking into the jaws of death." For apparently reckless bravery in the presence of almost certain disaster, both would seem to be paralleled by the act of the zic-zac, or crocodile bird, which walks calmly into the open mouth of the crocodile and picks food from the remnants left between and upon the monster's teeth. To a being of man size the open mouth of the crocodile with its yawning red cavity and its wicked-looking teeth is a threatening and horrible sight. To a bird which is small enough to walk in at that open door it must seem enormous. Should those jaws close, that would be the end of the bird. But they do not close. When the crocodile has stretched himself on the bank after a full repast, he opens his jaws and lets the bird walk in and help itself to what is left. The reason for this is said to be partly the comfort of having his mouth kept clean with so little trouble to himself, but chiefly because between the bird and the crocodile exists one of those odd partnerships of which we shall find a considerable number in Nature. The bird gets its living from the flies and other insects which lodge in the crocodile's skin, and even from the food in his mouth; it makes its return by warning the crocodile of any approaching danger. At the first hint of such danger it flies away, uttering its sharp "zic-zac, zic-zac," and the crocodile shuts his jaws with a snap and rolls over into the water.

ARCHER FISH, SHOOTING JET OF WATER AT INSECT

By this means the archer fish of the East Indies is said to bring down his prey. The jet of water knocks the insect into the water where the fish can get it.

THE FISH THAT SHOOTS

Of the archer fish it has been facetiously remarked that he is the only creature except man that shoots. He prowls along the banks of a stream until, according to the story, he sees on a low-lying leaf a nice fat, inviting insect which he covets for dinner. Then he shoots out a jet of water with an accurate aim which would be impossible to the ordinary fish, for fishes' eyes, with this and one other exception, are not so formed as to enable the fish to see clearly above water, and by that jet of water brings down his prey. I have never seen this fish on one of his hunting expeditions, and you will probably never see him, for he lives in the waters of the East Indies; but there are people who have seen him, and they vouch for the truth of this extraordinary story. It is even said that Malay Islanders keep archer fish in aquaria for the sport of watching their accurate marksmanship, but that seems like stretching our credulity a little too far.

PLANTS THAT CATCH AND EAT INSECTS

It is a commonplace for insects to get their living from plants, but for plants to turn the tables and catch and eat insects is unusual. Yet a considerable number of plants do so. These plants for some reason do not succeed in getting from the soil the usual and necessary amount of nitrogen to manufacture their protein food. If they could step out of their places as moving creatures can, and eat other plants, they might be able to get along without trapping members of the insect kingdom. But a plant cannot very well catch and eat another plant. It must devise some means of catching one of the moving creatures of the air which has taken its food from nitrogen-supplied plants and so will pass along its supply. When plants

are forced by the lack of nitrogen in the soil to this extreme measure, they are becoming meat eaters. It is interesting to notice that they become meat eaters for just the same reason that man and the carnivorous animals become meat eaters. They cannot live on starches alone, any more than man can live on (starchy) bread alone. So with the enterprise that marks always the struggle for existence, they set out to catch their meat.

Members of the sundew family often live in marshes and bogs. They do not find nutritious soil in which to root. They have on their reddish green leaves hairs with a swollen gland at the head of each, a gland filled with a sticky fluid which makes them glisten in the sunlight "as if fresh with moisture from the morning dew." Hence the name of sundew, and hence their deadly attractiveness to the passing fly. That glistening substance is probably a drop of honey; he must make for it. Make for it he does, but as soon as he tries to drink the honey, the hairs close about him, as you see them closing in the picture, and he is pulled toward the center of the leaf. Over him is poured from all the glands an acid secretion very like the gastric juice as it appears in animal stomachs, which prepares him to be eaten and digested by the plant. It is hard to think of the hairs having strength enough to hold a struggling insect, but they do it, pouring on more fluid the harder he struggles. "In the course of half an hour all the hairs of the leaf, about two hundred, attach themselves to the body, and when they unbend a few days later, they reveal nothing but a few indigestible remnants."

Pitcher plants are among the most common of the American insect eaters. Their pitchers, formed by the leaves of the plants, are closed at the bottom with the upper part covered by a half-closed lid. The leaves bend back easily to allow the insect access to the sweet sticky fluid on the hairs that line the inner walls; but they project in a way that prevents him from crawling out. He tumbles into the liquid with which the pitcher is partly filled and comes to death by drowning. The liquid acts somewhat like a digestive juice, and the food is gradually absorbed into the tissues of the plants.

A PLANT WHICH SETS AND SPRINGS A TRAP

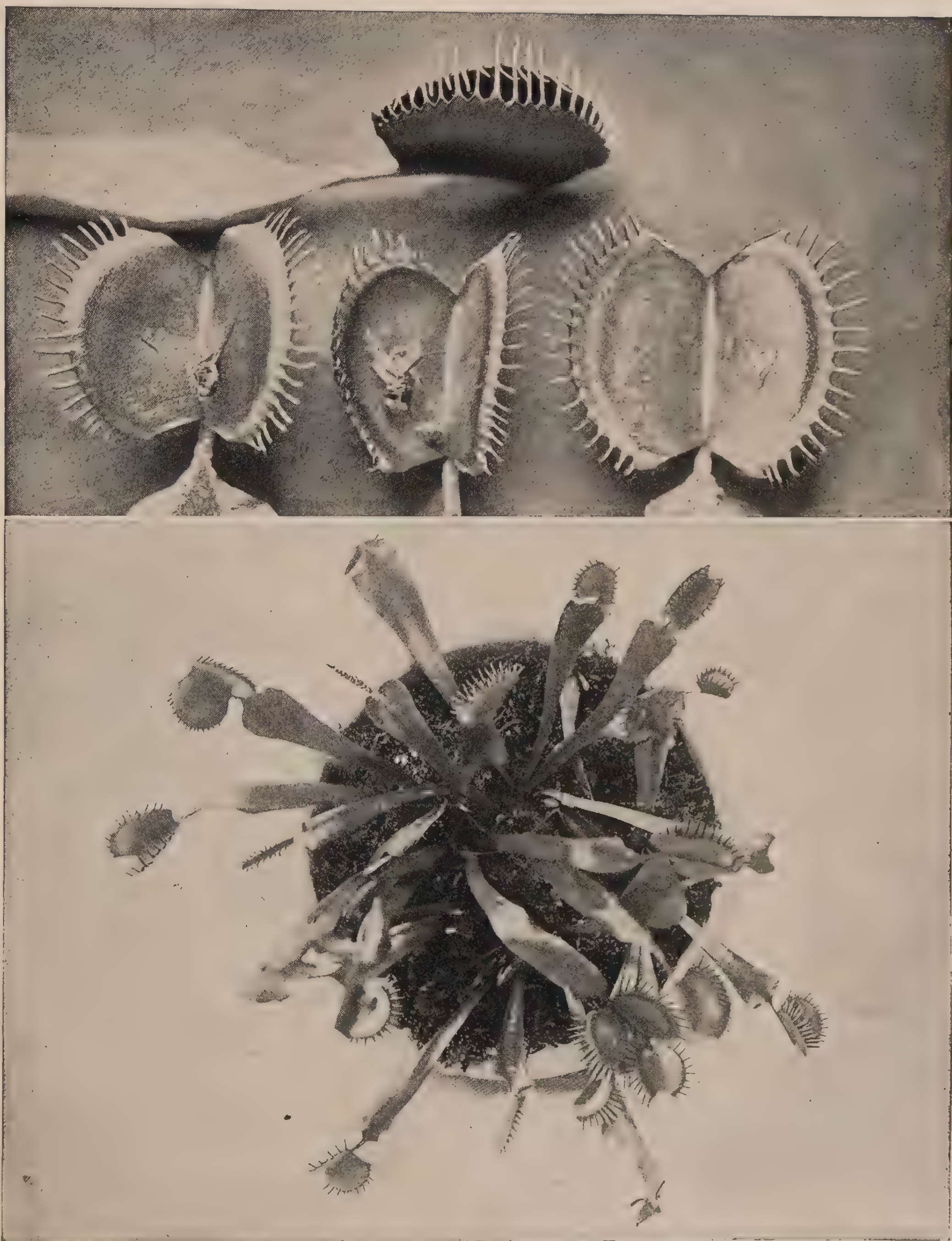
No plant works with a more ingenious and perfect mechanism in its business of catching insects than the Venus's-flytrap, found wild, it is said, only on the coasts of the Carolinas. The picture illustrates perfectly its method. The leaf trap consists of two halves with a series of teeth along their edges. On the surface of each half are tiny nerve hairs. Let an insect flying over it in search of honey touch one of these hairs, and instantly the halves spring shut on their hinge, the slightly curved teeth interlocking closely, as you see in the closed leaf at the top, in such a way as completely to imprison the visitor. It takes from ten to thirty seconds

Photos by S. Leonard Bastin

SUNDEW PLANT CAPTURING FLY

The passing fly is attracted by the glistening liquid on the sundew leaves. If he touches them, his fate is sealed, for he will be pulled in to the center of the plant.

A PLANT THAT TRAPS AND EATS INSECTS



Photos by E. F. Bigelow

VENUS'S-FLYTRAP AS IT SETS AND SPRINGS ITS TRAP

to shut the trap completely. The plant may take days thoroughly to digest the insect; then it opens to set its trap again for the next unsuspecting wanderer. It is a curious fact that if a stone is taken by mistake instead of an insect, the trap will open within a few hours and drop it out.

WATER PLANTS THAT FISH WITH TRAPS

Bladderwort is a plant that floats near the surface of the water, as innocent in its flowering beauty as any plant which has its roots firmly in the ground and draws its nourishment therefrom. But in some remote period bladderwort found that it was not getting enough of the right kind of food through its roots, and so in some mysterious way it set about turning its roots into the bladders or traps by which it catches its prey. These little bladders have spring doors which swing in before the minute fish or water fleas as they swim in, but swing shut after them, not allowing them to escape. By no means can the door be opened from the inside. The tiny fish or insects are securely imprisoned, to serve as a very necessary meal for the plant.

A HUGE MOUTH — A TINY THROAT

The size of a creature is no index of the size of the food it will eat. A whale has the biggest mouth in existence and lives on the smallest of sea creatures. The mouth of the whalebone whale is said to be fifteen or sixteen feet long and is of great width. He feeds on tiny shellfish which float in incredible numbers in arctic waters. As he plunges through a part of the sea where there is a host of these appetizing creatures lying in bands across the water, suddenly he opens his mouth and hundreds of them are engulfed. When he opens this huge cavern it engulfs an enormous quantity of water as well as food. But the whale does not wish to hold the water which he has taken in with them. He does not have to. Across his mouth there hangs from the upper jaw a fringe of hundreds of horny plates of whalebone (baleen) so closely set that they form a wonderful natural sieve. The whale lifts his huge tongue, which weighs a ton or two, and slowly forces the water up and out through his open jaws; but while the water can pass through the whalebone strainer as easily as water through a sieve, the living mouthful of crustaceans remains. With a mouth of this size it is one of the surprises of animal structure that the gullet through which this food will pass to the stomach is only an inch and a half wide. It need not be larger, for the food of the whale is composed of such tiny fry of the sea that an inch and a half (if this surprising figure is actually correct) is ample for its accommodation.

Readers of an older generation will remember the argument that raged among scientists and Bible students as to whether a whale could have swallowed a man. The whalebone whale could not, but the sperm whale, which has a mouth of the same size, has a gullet capable of swallowing a six-foot cube. So a Jonah might have been not only six feet tall, but might have gone into the whale's stomach with both arms extended to their full width.

FISH THAT GO A-FISHING

The whale catches his dinner by the simple method of swimming into a school of little creatures and opening his mouth. Not all sea dwellers are so equipped. Nor is it sufficient for them to wait hopefully and expectantly for food. Mouthfuls do not walk into mouths without some tempting reason.

The angler really goes a-fishing. He is a curious-looking creature, more than two-thirds of him consisting of mouth and stomach, if we except the fins. From his head protrudes the waving "pole" with soft fleshy knobs, which serves him as pole, hook, line, and bait serve the fisherman. Unwary little fish, moving about in the water, see these waving knobs, which look as appetizing as any seductive bait. In some of the deep-sea anglers, at least, the knobs are luminous, so that they are doubly attractive in lighting the little fish to the angler as well as looking good to eat when he arrives. But when he does arrive he is pulled swiftly into the voracious mouth. The angler of our northern waters does not even trouble to swim about, waving his bait. He finds it simpler and more effective to lie among the seaweeds, almost concealed by his protective coloring, waiting patiently for passing fish to be tempted within sight and range.

FISH THAT FISH WITH POLES

ANGLERS WAITING FOR THEIR PREY

The angler is one of the most remarkable of our fishes. On its head it carries a pole with a knob which it waves as bait. The inquisitive little fish which seizes the soft knob finds itself pulled into the wide-open jaws. The fishing frog angler, from three to five feet long, is found in European and American waters. The tiny "frogfishes" in the lower corner (left) are deep-sea fish, only two or three inches long, belonging to the same family. Their knobs are often luminous, giving the effect of going fishing with a lighted lamp.

It is interesting in connection with our earlier story of deep-sea life to see how the little anglers, at the left of the picture, are very similar to their big brothers of the surface waters, but are compressed to a length of two or three inches, in contrast to the three to five feet of the others. All of the deep-sea fish have huge mouths and stomachs which will expand to accommodate a good reserve store of food. Apparently it is a case of taking whatever can be gotten while the "getting is good," in anticipation of frequent times when food supply will not be so available.

MOUTHS FOR CATCHING FOOD

The more we examine the mouths of living creatures, the more we realize the many functions which these mouths must perform. Our own mouths prepare the food for the stomach and in so doing pass along to us the report of its taste. Insect, bird, fish, and animal mouths more often than not must catch the food as well as eat it. Sometimes it is the tongue, as in the case of the chameleon, the toad, the anteater, which can shoot out an extraordinary distance and bring in food to the waiting mouth.

Insects have varying food habits that show themselves in the kinds of tools with which Nature has provided them for acquiring food. Vegetarians among the insects have jaws with which to cut off leaves and stems and chew them. Those which eat even harder stuff have jaws so powerful that they can grind and crunch their food, while others, like the honeybee and the butterfly, have their mouths modified into long sucking organs that can reach far into a flower or into animal flesh and find the nectar, sap, or blood which the insect craves. Biting, boring, and sucking seem to be the favorite insect methods of food getting, and our photographs show some of the marvelously effective adaptations of parts to those ends.

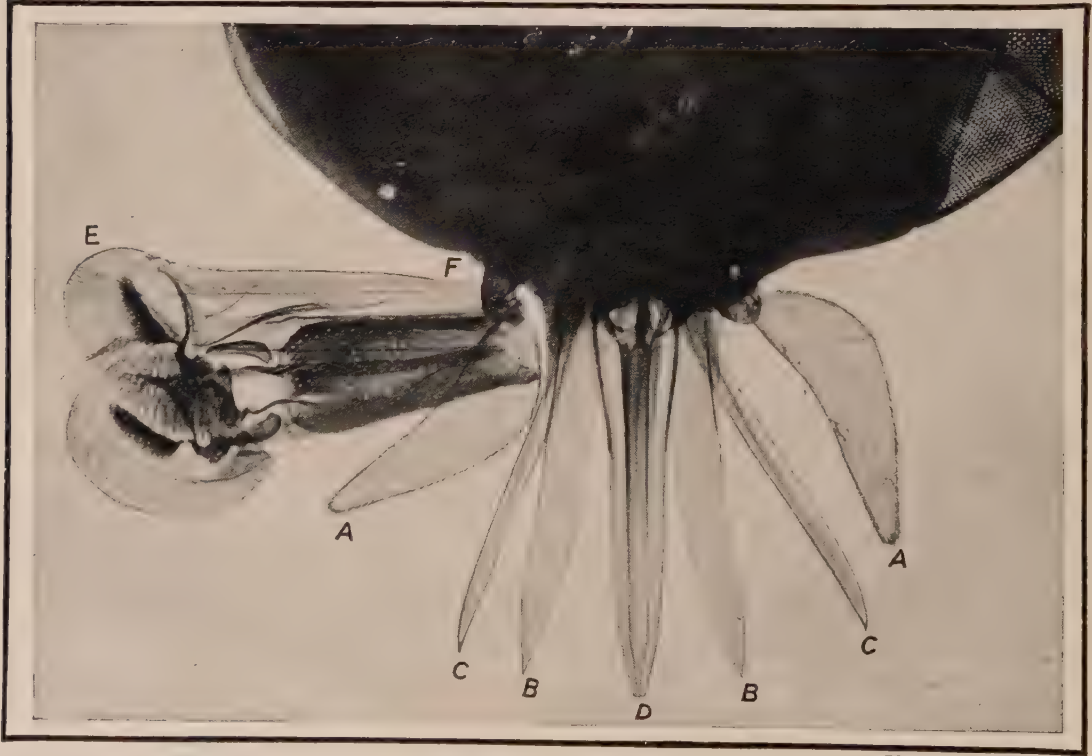


Photo by E. F. Bigelow

THE TOOL KIT OF AN OXFLY

AA. Feelers, to find a tender spot in the ox's skin. BB. "Scissors" to cut a hole. CC. Sharp, barbed needles with which to push tube D in or pull it out. D. Tube through which to drink the ox's blood. E. The "proboscis" that protects these parts, swung to one side on the hinge F.

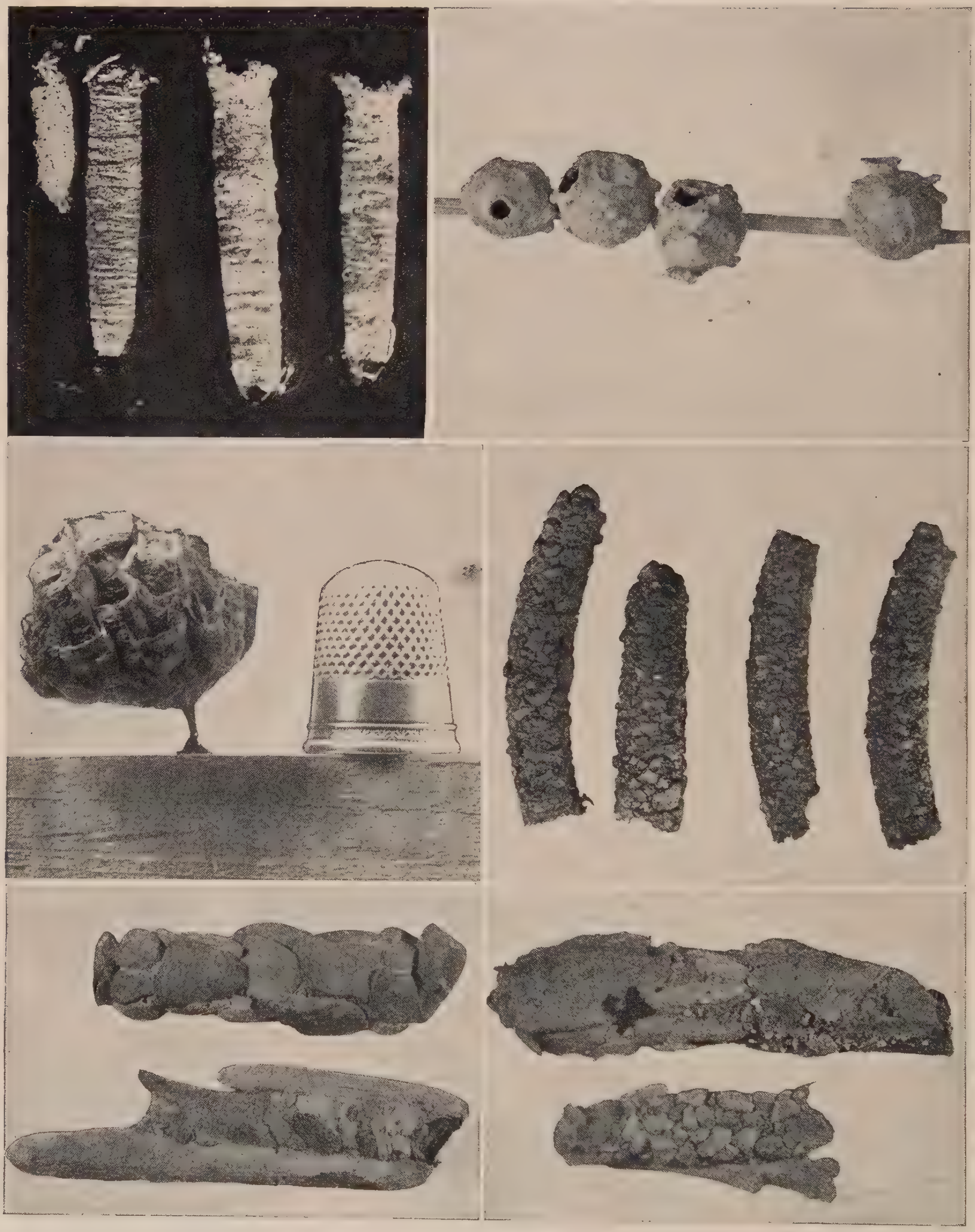
HOW SOME INSECTS GET FOOD

Photos by E. F. Bigelow

MOUTHS WHICH CATCH FOOD AS WELL AS EAT IT

Above, the long snout of the chestnut weevil, sharp as a drill; in the center, the soft tongue of the housefly; below, grasshopper's jaws.

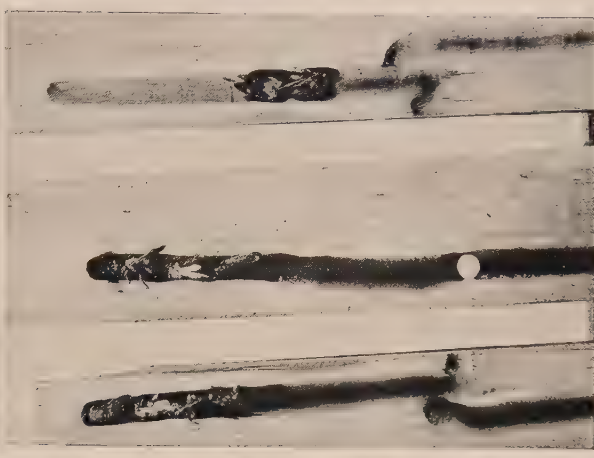
WONDERFUL INSECT HOUSES



WHEN WORM AND WASP TURN BUILDER

Wasps built the paper house shown next the thimble and the round mud house in the upper corner. The other houses are worm houses, houses of stones or grains of sand, fastened and lined with silk, which the "case" or caddis worm builds about his own body, to keep little fish from eating him. This house he carries on his back. One day he goes in and shuts the door, and before long he comes out, not a worm at all but a caddis fly.

THE SAWS OF A SAWFLY



THE CARPENTER BEE AT WORK

INSECT CRAFTSMEN

A worm that travels about in a portable stone house of his own building — a wasp that is a skilled mason — a bee that builds a cement house — a carpenter bee that builds a six-room apartment — a diligent wasp that worked forty-two hours with only ten minutes' rest — a bumblebee that builds a house of bread — a wasp that manufactures paper — a spider as engineer, bridge builder, hinge maker, and trap setter.

A CRAFTSMAN is a workman who practices his trade or craft with skill. When you have been introduced to the group of insect workers that I am now going to present to you, I think you will agree with me that they earn the title of craftsmen. Some of them go beyond the stage of craftsmanship and may be ranked as artists, if judged by the beauty of their productions. All their work has to do, as you will notice, with the prime necessities of life, — food, shelter, self-defense, and the rearing of a family. Some of them work in unions, some go about their business alone. All work hard and fast, for insect life is short and every moment must be utilized.

INSECT MASONS

House building is a common occupation among insects. There are houses of mud, houses of paper, houses of stone, houses of wood, houses of wax — all sorts and conditions of houses. The first housebuilders we shall meet are the masons, those who work with mud, stone, or similar materials.

THE CADDIS WORM CARRIES HIS HOUSE ON HIS BACK

As we sit some day quietly watching the bottom of a pool or brook, we are likely to see a short hollow stem walk away. It looked like a mass of stones or sand, but before our very eyes it seemed to take to itself legs and walk slowly over the pebbly bottom or climb some water plant. This is the caddis worm, walking about in his portable tube house. Unprotected the caddis worm, which is the larva of the caddis fly, would be a luscious bit of food for a hungry water creature. So he sets to work to build a protecting house for himself, within which he may pass his days in comparative safety. He makes for himself a silk tube or case, and to this he attaches, as he weaves it, bits of stone or sand. The result, as shown in the pictures on the opposite page, is a little stone or sand house, with both ends open for air and water to pass through. Its very irregularities are its highest art, for it looks like the earth stuff of which it is made and would never attract attention among the loose pebbles of the pond or river bottom.

Some caddis worms choose leaves, not pebbles, for their houses, but more of the common species are regular little masons. When the time of their active life in their wormlike stage is over, they close the doors of their houses as the caterpillar shuts himself into his cocoon, to emerge in a short time as full-fledged caddis flies, leaving their houses behind them.

THE MASON WASP

The mason wasp actually goes through the successive processes of a mason in building her mud house. You may know her better under the common name of "mud dauber." This steel-blue wasp, with the very long threadlike waist, is abundant in early summer about the edges of puddles, working industriously, mixing her saliva with the mud so as to make her plaster more firm. Then with the pellet of mud held firmly she flies to the under side of the rafter, or whatever protected place she has selected for her nest. Here, using her jaws as trowels, she makes a mud tube about an inch long; each mud pellet making almost one coil of the tube. She may build a half dozen of these tubes side by side, later plastering all firmly together. Before she lays the egg which is to go in a tube, she fills that tube with spiders, so that the young when hatched will have sufficient food to grow to adulthood; then each can gnaw its way out of its comfortable compartment to the greater freedom of the open air. The wasp's nest is, like many of the insect houses, one of Nature's nurseries.

THE BEE AS MASON

The mason wasp seeks damp earth, taking it and using it as she finds it. She depends on its drying to the necessary firmness. "If, by some accident, the rain strikes it, the whole becomes soft and falls to pieces." This is doubtless the reason why sheltered spots, under the eaves or in barns, are often selected for her building operations. The mason bee, another builder in clay, works like the bricklayer, mixing mortar and plaster from fine dust by adding water. She passes by any damp earth, and selects fine, dry dust, which she mixes into pellets with her own saliva, making a quick-hardening cement. She also brings to the spot where she is laying her foundation bits of grit and stone, laying them carefully, and then plastering them together with her pellets of mortar. In this way she economizes labor by using material already at hand and adds to the firmness of the dwelling.

There are stories which are not so pleasant of the huge ant hills built, tunneled, and lined with masonry by the termites, huge insects of the Amazon regions which resemble ants in their appearance though they do not belong to that family. But the method of masonry is in all cases much the same, and our own wasps and bees illustrate it as well as any of these armies of creatures that infest the tropics and live in hills many feet high. Interesting as these termite pyramids are, they are no more "wonders" except in their combined size than the houses so skillfully and rapidly built by our own little neighbors of the insect world.

THE CARPENTER BEE

Man builds houses for himself *and* his family; the insect builds for children, which, in all probability, she will never see. The industrious carpenter bee, whose tunnel is laid open for our inspection by Dr. Bigelow (page 145), builds a six- or seven-room apartment for her children. With her strong jaws as tools she sets to work in a post or any piece of dry wood, seasoned to her purpose. It is one of the inconspicuous wonders of selection that she never by any chance selects living wood, but always chooses as wisely as any human carpenter that which will yield the best results. Sawing away with her jaws she makes a hole in the wood, bores in a little way, then turns at right angles and sinks a shaft deep into the post. As fast as she clears it out, she carries the sawdust to the entrance, piling it there for future use. Then with sawdust cement, made with her saliva, she closes each room, — when she has filled it after the fashion of the mason bee and the wasp with food for her young and has laid an egg there, — until the whole apartment is finished and tenanted with eggs soon to hatch. Sometimes, it is said, she makes a second door at the far end of the gallery, so that the first rooms built will have direct access to the world. The mason bees and wasps could start and finish a

cell in a single day, but it takes the carpenter bee a long time to tunnel the shaft and build and stock and partition off her rooms, one by one.

There are carpenter wasps as well as carpenter bees. As an example of the toil involved in insect carpentry, Mr. and Mrs. Peckham tell of a carpenter wasp which worked for forty-two hours with only ten minutes' rest, and had dug out in that time fifteen and a half inches of tunnel. Wasp or bee, mason or carpenter, all work with prodigious industry and perseverance.

A HOUSE OF BREAD

A most interesting house for babies and young children is built by the bumblebees. It consists of a special kind of beebread, made by mixing the pollen and nectar of flowers. Some species place this in rough masses upon dead grass on the surface of the ground. Then at intervals the eggs are laid upon this pile of bread. When the eggs hatch, each young larva eats into this mass until it is full grown. Then it spins about itself a cocoon and soon emerges an adult insect. Later these deserted cradles are stored with honey. It is because of this manner of formation that the bumblebee cells are so irregular.

A BUILDER WHO IS A GEOMETRICIAN

The honeybee is a geometrician. In building its cells, either as cradles for the young or as vessels for the storage of honey, it begins by building a base of low triangular pyramids. Upon the opposite sides of this base it builds horizontal six-sided (hexagonal) prisms. It thus produces a tenement house with the little rooms about equal in size and almost mathematically perfect. The building material, the wax, is produced by self-elected bees gorging themselves on pollen and honey, or on honey alone. After a little while they secrete the wax in flakes, which are gathered up by other workers and built into the cell walls.

Since the comb of the honeybee is so familiar, and since the reason for its particular shape of cell has been the subject of much discussion between naturalists, we quote at length the observations of Edward Step, a British observer and student of bee life. "A considerable amount of honey is converted into only a small quantity of wax, and therefore the workers use it with parsimony. There is no waste, and they have learned to make the maximum structure out of the minimum of material. That is the reason for the six-sided shape of the cell. . . . If the individual cells of the bee-comb were fashioned separately, and then a number of them were brought together under equal pressure they would form hexagons; but they are not made separately, but are built in mass, and every part of the walls of one cell forms part of the wall of a neighboring cell. This is even so with the base of the cell, which forms part of the base of three other cells on the other side of the comb. To human artificers the task would necessitate a resort to mathematics, but the worker bee issues from the chrysalis fully competent to undertake the task without swallowing the books of Euclid, and without even parental instruction. Pure 'rule of thumb' practice, but even so the mathematicians have failed to find any flaw in its results." Mr. Step goes on to tell the familiar story of how mathematicians undertook to figure out the angles of the basal pyramids as they should be from the ideal standpoint if the least possible amount of the precious building material, wax, was to be used in their construction. Employing "infinitesimal calculus" the mathematician figured the problem through and arrived at a set of figures almost but not quite those of the angles as measured. This was considered a wonderful agreement between theory and fact, until another mathematician took up the problem and arrived independently at exactly the figures as measured. The matter was then investigated, and it was found that the first mathematician had made use of a logarithm book with an error in it, which accounted for the difference. So the bees were right, and in a sense they corrected the logarithm book, for they pointed out its error instead of its pointing out their deviation from the ideal line. How many modern buildings, we wonder, would be built with such flawless accuracy!

It is interesting to note that no one bee builds a cell, but each is built by a number of workers doing a little in succession. As the bees work away on adjoining cells, one wall fits into another and so each cell becomes hexagonal.

THE WASP AS PAPER MAKER

Long before man made paper out of wood pulp the wasp was shaving off wood fibers with her strong jaws and kneading them into a pulp moistened with saliva, then spreading it out in thin sheets of wasp paper for her nest. If it is to go underground, that is all she does to it, and it serves its purpose as well as our paper serves ours. But if it is to be aboveground, she puts on with her tongue a waterproof coating and produces a creditable weatherproof material. In the building of the community house — for wasps pack their nests with a large company of workers — one layer after another of paper is added. In putting the house together in this way, wasps take advantage of one of the fundamental principles of ventilation, that layers of material with air spaces between will hold the heat and make for an even temperature. It is curious to find the laws which mankind has arrived at by process of long experience and careful reasoning adapted and put in practice by members of the insect world without any instruction, probably as a result of racial experience. Like the bee, the wasp builds an elaborate set of cells with separate accommodations for one hundred or one hundred and fifty dwellers, all in concentric pattern, with no more apparent effort than as if a single cell was in process of construction. Both are artisans of no mean skill.

THE SPIDER AS ENGINEER

Chief among insect craftsmen stands the spider — spinner, weaver, builder, and engineer. Here is a piece of engineering skill which is close at hand for every one of us to observe.

"An elaborate network of steel cables, 336 feet in height," writes Mr. Murphy, Associate Member of the American Society of Civil Engineers, "erected in place by one man without the assistance of hoisting engine, block and tackle, or other mechanical accessories, would be a marvel in the construction field, and would be written up in the greatest detail in the technical papers. Yet the equivalent of this process is going on unnoticed in the angles of our back porches and in the trees and shrubbery, every day during the autumn. There is no more industrious or ingenious builder in the world than the spider, whose web furnishes an example of the highest skill, from an engineering point of view, of the same type of engineering that is displayed in skyscrapers and bridges." In comparing the work of the spider and the man as bridge builder it should be remembered, however, that a steel cable cannot be floated in the air like a cobweb strand. As the young spider throws out thread and counts on it as a balloon, similarly the web-spinning spider counts on the carrying power of air, thus getting the benefit of a kind of hoisting engine.

Bearing in mind the fact that an orb weaver spider can complete in an hour or two by its own efforts a structure as strong and efficient, in proportion to its size, as the framework of a great skyscraper or suspension bridge, let us follow out the building of such a web as it has been patiently watched and carefully sketched for us in the accompanying pictures.

LAYING THE FRAMEWORK

As an Indian juggler is made to appear to throw a rope into the air and then climb it, this spider throws out her fly line with glue on the end, waits till it catches somewhere, then draws it taut and runs across it. The first line of the bridge has been laid. With this done other supporting lines can be laid, and in the second figure these foundation lines are shown with the first radii laid across. "The first step in laying these radii," writes John Henry Comstock in "The Spider Book," "is to stretch a line across the open space in the framework so as to pass through the point which is to be the center of the orb. In doing this the spider may start on one side, and be forced to walk in a very roundabout way on the outer framework to the opposite side. It carefully holds the new line up behind it as it goes along, so that it shall not be entangled with the lines on which it walks. . . . The spider then goes to the point where the center of the orb is to be, and fastens another line there, it then walks back to the outer framework spinning a line as it goes. . . . In this way all of the radiating lines are made, the spider returning to the center of the web to begin each radius."

HOW A SPIDER SPINS HER WEB

FASTENING THE THREAD

FOUNDATION LINES IN PLACE

SPOKES IN AND CENTER HUB WOVEN

SCAFFOLDING TO HOLD SPOKES STRAIGHT

WEAVING FROM THE OUTSIDE IN

THE WEB COMPLETED

A REMARKABLE TRIUMPH OF ENGINEERING SKILL
The web of an orb weaver at six successive stages, as described in accompanying text.

As the last spokes or radii are put in, the spider begins on each return to the center of the web to strengthen the hub, netting it together by threads laid or drawn tight around the center.

"A few seconds after this," says an observer, "the spider commences one of the most wonderful of the many astonishing features of geometric web-spinning, inasmuch as it apparently demonstrates foresight and the possession by the spider of reasoning powers which enable it to use the best means to accomplish the end in view." It fastens a thread near the right upper center, then by supporting itself on the spokes of the wheel and working toward the left, it puts in near the center the spiral line shown in the fourth picture, the object of which is, like that of a scaffolding, to keep the spokes firm and to hold them at the proper distances apart. Comstock has called this the "spiral guy-line." With the framework completed it begins stretching on the spokes what is to the spider the most important part of the web, the sticky elastic line, laid from the outside in, as it is shown in the two lower pictures, on which the unsuspecting insect will find itself entrapped. For while we admire the spider's work as a bridge, it is a trap, constructed for the purpose of that important part of life's business, food getting.

THREAD STRONGER THAN IRON

Now that we have watched a spider through the spinning of a web, let us go over the process to see where the specialties of craftsmanship occur. First, the materials used.

The spider makes no requisitions on outside manufacturing plants for her building materials. Her factory is in her own body, within which she makes one of the finest and strongest threads in the world. The factory is so small that it is hard to make a mental picture of it, but in the drawing it is shown many times enlarged. Through six spinnerets or spinning fingers, each with something like a hundred holes, a glutinous secretion pours out, which hardens as it meets the air into one slender silken line. This silken thread "is one of the most efficient mechanical implements known to engineers, viz., a strong elastic thread. . . . There are few substances that will support a greater strain than the silk of the silkworm or the spider, careful experiment having shown that for equal sizes the strength of these fibers exceeds that of common iron. But, notwithstanding its strength, the spider's thread alone would be useless as a mechanical power if it were not for its elasticity. The spider has no blocks or pulleys, and therefore cannot cause the thread to divide up and run in different directions; but the elasticity of the thread more than makes up for this, and renders possible the lifting of heavy loads."

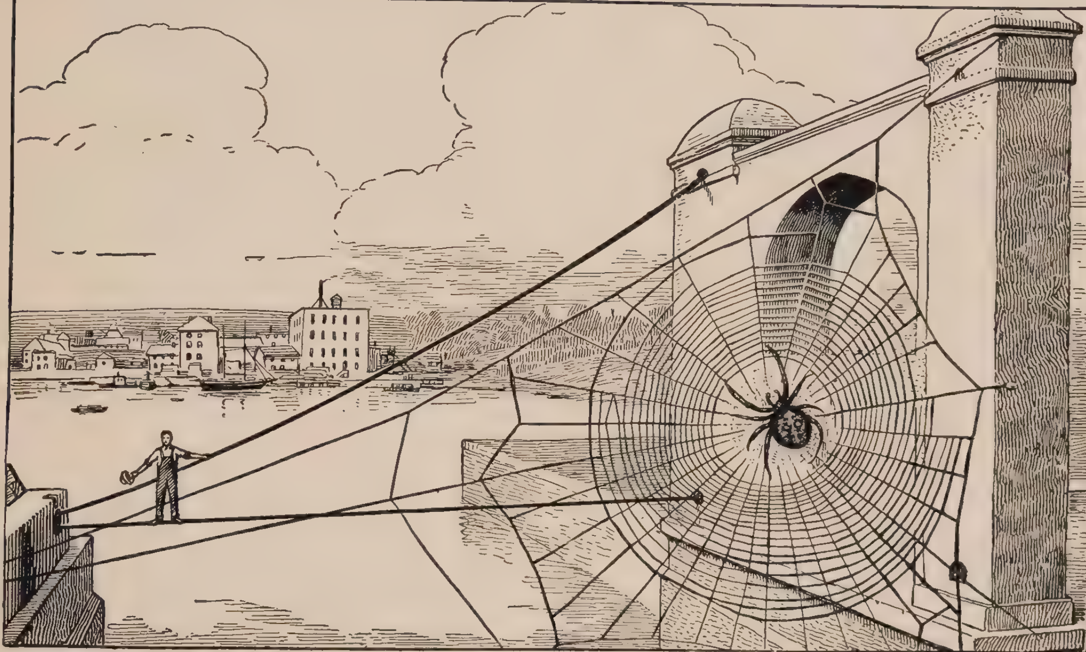
Of the fineness of this thread astronomers give testimony. Spider thread is used by astronomers in their telescopes, writes Sir E. Ray Lankester, of England, for the purpose of giving fine lines in the field of view, by which the relative positions of stars may be accurately measured. "For a century astronomers desired to make use of such lines of the greatest possible fineness, and procured at first silver wire drawn out to the extreme limit of tenuity attainable with that metal. They also tried hairs (1-500th of an inch thick) and threads of the silkworm's cocoon, which are split into two component threads each only 1-2000th of an inch thick. But in 1820 an English instrument-maker named Troughton introduced the spider's line. This can be readily obtained three or four times smaller in breadth than the silkworm's thread, and has also advantages in its strength and freedom from twist. . . . As to the limits of the tenuity of the threads of gossamer there are no direct observations. Probably they are often as fine as the 1-15,000th or 1-20,000th of an inch in diameter."

Another scientist has computed that "it would take four millions of the threads of a particular spider he was studying to make one hair of his beard."

THE MATHEMATICAL SPIDER

"While the spider is ignorant of the principles of mathematics, still she has inherited from a long line of web-weaving ancestors the ability to execute in an hour's time, alone and unaided, perfect geometrical figures constructed on the highest mathematical principles. . . . Any mere human being who had to build a structure of the same size in proportion to its own would require a small army of laborers, and two or

IF THE SPIDER WERE AS BIG AS A MAN



SPIDER AND MAN RUN A RACE AS BRIDGE BUILDERS

The man may well take off his hat to the spider. While he has been placing two supporting lines, the one on which he stands and the one against which he leans, the spider has almost completed his web. A picture on the page of a book can only begin to suggest what the spider could really do if he were man-size. His "reach" is three-quarters of an inch, and he builds a bridge two feet across. Let his "reach" be nearly seven and a half feet, — that of a man standing on tiptoe with arm uplifted, — and he would build in two or three hours a bridge two hundred and forty feet across, manufacturing meanwhile all the material from his own body.

THE SPIDER'S FACTORY AND MACHINERY

In the center of the picture (above) is the back part of the spider's body with (in the lower right-hand part) what looks like a piece of string loosely dropped in loops and twists. This is the factory where the spider makes his thread, pushing it out through six "spinnerets" or spinning fingers (shown below), each with a hundred holes. A single spider's thread is made up of six hundred threads as they push together to make one strand, when they have been thrust out through the six hundred holes. Do you wonder that this tiny thread is as strong for its size as iron? At the right (above) are the marvelous fingers with which he ties his knots, with below and on the web at the left the glue which makes the web hold to its supports and also makes it a trap for catching insects.

three days' time, as well as all kinds of mathematical and mechanical aids."

It would be too technical a matter to enter into all the examples of a counterbalancing of stress and strain, of economy of material, and skill in construction presented in a web as the engineer examines it; but the reader may like to follow the conclusions of a civil engineer on the reasons why the spider can accomplish what she does. "The spider is able to build this complex structure single-handed and without the aid of mechanical accessories because of just two natural faculties. One is her ability to drop vertically with a line as she spins it, and the other is her skill in climbing in any direction, spinning a line as she goes and holding it out with one claw so that it will not foul with the line she is climbing on. The fresh-spun line is very elastic. It is often stretched to three or four times its natural length and then snapped into place after the builder has climbed around some corner in the structure. In this process she shows herself to be an excellent judge of distance, knowing just when to quit spinning and to begin stretching the line." One wonders how in that tiny body and pinhead-sized brain these qualities of good judgment and mechanical ability are implanted. Before the subject of mind as it appears in Nature, we halt again and again, each time with a new sense of surprise and admiration.

THE TRAPDOOR SPIDER AS HINGE MAKER

We have read in "Life in Three Zones" of the trapdoor spider, which tunnels out a home for herself in the earth. Interesting in itself from its careful construction and padded silk lining, this home becomes a marvelous bit of craftsmanship because of its hinged door. When the spider has made her tunnel she throws a covering of silk over the opening; then she covers that silk with a layer of gravel. This is so cunningly done that it takes careful and painstaking search to discover in a California sand bank any sign of a dozen or more such tunnels. There are various kinds of doors, some thin and some thick, but for each, as we understand it, she cuts the silk of the door for two-thirds of the way round, leaving the remaining third uncut, to act as a hinge. Are we not right in saying this is the first hinge in the history of the world? It is a good hinge, this strong, tough bit of pliable silk, and it works well. For some species of trapdoor spiders it lifts a light "wafer door," a "simple flap of silk and dirt"; for others "a thick stopple, with its edges accurately beveled to fit the beveled opening of the tunnel." Sometimes the tunnel is in the form of the letter Y with two doors; sometimes there is a system of double doors at the entrance, for added protection against the invading enemy. But always there is the elastic, strong hinge.

As the spider family excels all others in conquering, for the purposes of its life, earth, air, and water, so it seems to have put itself at the head of insect craftsmen with its wonderful web and its clever trapdoor. While this chapter can only hint in its brief space at the marvels of insect structure, it can send you out to study them for yourself, for insects are our closest and most abundant neighbors. In later stories we shall enter even more fully into insect life, learning how they see and smell and touch in chapters on "The Five Senses—and Others."

THE WORLD'S HIGH JUMPERS

HOW INSECT ATHLETES MAKE THEIR RECORDS

LEGS FOR SWIMMING, JUMPING AND CLIMBING

Left : (top) beetle's oar leg, (bottom) grasshopper's jumping legs. Right: cricket's legs.

Photos by E. F. Bigelow

THEY MUST BE ABLE TO JUMP TWENTY, THIRTY, FIFTY TIMES THEIR HEIGHT

Before we leave the subject of insect activities, it is interesting to consider their extraordinary powers of locomotion. Many insects fly; many can take phenomenal leaps through the air; others swim; and still others seem to walk on water, so lightly and easily do they skim the surface. Look at the length of the fleas' legs and the many joints and the queer little body above them, and you understand how they hold the world's record in high jumping. The beetle swims and "feathers his oar" with a twist of the leg. Cricket and grasshopper legs are shown to have spikes on the sides like those of a telephone lineman, with hooks at the end to catch with.

Photo by Wm. L. Finley

NEST AND EGGS OF KINGBIRD IN POPLAR TREE

"Whose habitations in the treetops even
Are halfway houses on the road to heaven!" — LONGFELLOW.

Photo by Wm. L. Finley

THREE YOUNG VIREOS

FEATHERED ARCHITECTS

Birds as nest builders — birds that build in colonies — a tailor bird that sews — a bird that makes felt — a bird that builds a cement house — nests that are good to eat — a bird that builds a playground.

"A bird's nest. Mark it well, within, without,
No tool had he that wrought, no knife to cut,
No nail to fix, no bodkin to insert,
No glue to join; his little beak was all.
And yet how neatly finished! What nice hand,
With every implement and means of art,
And twenty years' apprenticeship to boot,
Could make me such another?" — HURDIS.

TO see a feathered couple go about its spring task of nest building is to witness the perfection of busy, happy home making. Although constructed for only a few weeks' use as a temporary shelter for eggs and young, the nest of one of our song birds is a piece of craftsmanship of no mean skill. The architect that planned it knew how to select the right foundation, make use of the required supports, and build a cunningly constructed edifice from the materials which he had at hand. Estimated as a piece of ingenious and clever workmanship, well adapted for its purpose, a nest set in or swinging from the branches is worthy of our admiration. Considered as the achievement of a single builder or pair of builders having only their beaks and feet and legs as tools and only the materials they could find and transport for their use as supplies, it is a marvel.

Artist-photographers have fortunately relieved us of the almost impossible task of describing a bird's nest. To say that a nest "is

composed of grass, leaves, plant stems, fine roots, sticks, seaweed or perhaps bits of snake-skin, woven or fitted together into a cuplike structure, capable of holding eggs and young," is to present a true and matter-of-fact description of a nest with all the poetry left out. There is a charm of construction or position or both about the crudest nest which any one who has come upon one of these bird homes in an unexpected spot can testify. That a little creature which cares nothing for a home for itself should go to infinite pains for the making of this home for its dependent young is a sign of the instinctive forecasting of Nature, intent always on the carrying on of life. We have seen how the nests progress according to the bird's requirements for the protection of its young, from the hollow in the sand to the elaborate woven basket swinging from a limb of a tree. Of the birds of our own country, song birds are those which build the most elaborate and beautiful nests.

Photo by Wm. L. and Irene Finley

BLUEBIRD AT NEST HOLE IN APPLE TREE

WHERE TO PLACE THE NEST

Location is the first consideration. The bluebird places the nest in a hollow in a tree, forming a careful and well-made structure in the spot selected. Many of the birds take no such advantage of natural shelters but set their nests in what would seem precarious spots, did not the little builders test them out before they began and prove their suitability. Of the vireos' nest at the head of page 155, which Mr. Finley watched in its construction, he has written: "It was not a haphazard site they selected. They searched for positions and studied different places. Then at last they decided upon a hazel bush. Both began work, and they worked independently, each hunting moss and fibers and weaving them in to his own satisfaction. . . . The vireos built their nest in a good position, for it was entirely shielded by leaves. You couldn't see the nest from the front; it was roofed over with a big hazel leaf, and in hot or rainy weather the mother had this canopy over her head."

HANGING NESTS

Vireos and orioles are the two groups of American birds which build the beautiful pensile or hanging nests. These have often been compared with baskets, and have earned their makers a title to the crafts of basket makers and of weavers as well as of clever architects. It is quite a matter, when one thinks of it, to swing out from a branch a structure wholly unsupported at the bottom. The nest of the oriole swings freely, but that of the vireo is fixed. Both are examples of the principle of protective coloration followed in bird architecture. The less conspicuous the nest the safer its occupants. So nests usually harmonize well with their surroundings. The fact that this custom in nest building makes for concealment does not prevent its effectiveness from the standpoint of sheer beauty. The little architect selects perforce materials from his or her immediate surroundings, but chooses them with a nice eye for color. Friendly humans who have hung out pieces of string in an effort to help the builders of basket nests have almost invariably had the bright-colored

pieces rejected, while those of white and soft grays were gladly accepted. Of the nest of the red-eyed vireo Miss Stanwood writes in *The Craftsman:* "This bird works with so much dexterity, skill, and adroitness, and with such careful selection of materials that the wonderful little palace grows unnoticed and hangs there unseen until the leaves are gone. . . . The gray exterior of the nest harmonizes with the bark of the tree, and the green bird sitting on the nest, so still but so watchful, is almost the color of the foliage among which she sits. . . . To make a dwelling a harmonious part of its environment is a feat not accomplished by a great many human architects."

Bird writers vie with one another in admiring descriptions of the work of the Baltimore oriole, whose nest is said to be one of the most beautiful and skillful examples of bird craftsmanship in the whole world, not even excepting the strange and elaborate nests of tropical birds which are so much praised. Speaking of the oriole Blanchan says: "Among the best architects in the world is his plain but energetic mate. . . . Gracefully swung from a high branch of some tall tree, the nest is woven with exquisite skill into a long flexible pouch that rain cannot penetrate, nor wind shake from its horsehair moorings." Of its construction another writer has said: "Suspension strings are first firmly tied to the branches, these forming the warp through which the plant fibers, milkweed stalks, gray strips of bark, horsehair, or cord, are deftly woven. The completed structure is gourd-shaped, flaring at the bottom and always gray colored. . . . The perfection of their workmanship is proved by the fact that these homes sometimes endure the blasts of four winters."

Photo by Wm. L. Finley

GNAT CATCHER AT NEST IN CHOLLA CACTUS

KINDS OF NEST

The bird craftsmen of our own country may be roughly grouped according to their style of construction in big classes. There are the birds, like the bluebird, which construct their nests in natural cavities, in trees or elsewhere. There are those which make cavities in the trees which they select for their homes, among which are the woodpecker, the nuthatch and the chickadee. These are the carpenters of bird world, using their beaks as tools as the carpenter insects used their natural tools. There are the birds which burrow, digging themselves with beak and feet into a clay bank and hollowing out a passage, sometimes several feet long, at the end of which is a safe and retired chamber, furnished with straw, grasses, and down for occupancy. The kingfisher does this, as do also the bank swallow and other birds of allied families. There are the many birds which build open nests, on the ground, in woods or thickets, in branches of trees, variously fashioned of many kinds of materials. There are the birds which partially glue their nests to a wall, either with mud or with saliva, like the cliff swallow and the chimney swift. There are those which add a roof to the nest, like the ovenbird, or swing it like a hammock, like the vireo and oriole. This summary by no means exhausts the list, but it gives a little idea of the variety of construction, a variety well brought

out by a charming catalogue of familiar bird craftsmen by Eloise Roorbach in a story of "The Way of a Bird with its Nest."

"The vireos make a cozy pocket fastened in the fork of a small branch under the eaves of a leaf rooftree; the catbird designs a clever lattice nest of twigs; the robin is both carpenter and mason, building of sticks in a crotch of a tree and plastering with mud; the parula warbler gathers the long, gray, lacy lichens and fashions a swinging hammock open on one side; the chimney swifts glue wicker cradles to the brick wall; the kingfisher tunnels deep into a bank, working for two weeks before he has it deep and safe to his liking; the ground warblers make pretty little hermitage huts in the grass; the yellow-winged sparrow and the ovenbird build a roof of grass to keep out the rain; the marsh wren ties and weaves a clever little house among the cat-tails and rushes; the woodpecker drills industriously until he has a good-sized hole in the bole of a tree, then he lines it with down to make it warm and comfortable for the nestlings."

Photo by Wm. L. Finley

WREN'S NEST

Any one who has ever tried to find the nest of an ovenbird and finally had the rare good fortune to succeed in locating it knows how amazing is its invisibility, due to protective structure and coloration. Even when its location is known, the finding of it is no easy matter.

THE LABOR OF BUILDING

Of the labor involved and the material required in building one of the simpler nests only a persistent watcher can have any idea. One observer tells of putting out fifty feet of twine in short pieces, which was all used in the weaving of a nest. T. Gilbert Pearson watched a robin's nest from start to finish and then examined it in the late summer, when it had served its purpose and been abandoned. "In its building a framework of balsam twigs had first been used. There were sixty-three of them, some of which were as much as a foot in length. They served as the sills and studding of the house. Intertwined with them were twenty fragments of weed stalks and large grass stems. The red clay cup, the plastering of the house, which came next inside, varied in thickness from a quarter of an inch at the rim to an inch at the bottom. Grass, worked in with the clay while it was yet soft, aided in holding the mud cup together. Last of all came a smooth, dry carpet of dead grass. The whole structure measured eight inches across the top. Inside it was three inches in width and one and one-half in depth."

IN THE TROPICS

While the United States has within its borders the builders of some of the most beautiful and most remarkable nests in the world, some of the tropical countries can lay claim to having the most curious nest builders. It may be that the dangers to which tropical birds are exposed because of the abundance of animal life, frequently hostile, spur the birds on to more difficult and elaborate house building. The hanging nest, an excellent safeguard against snakes, is developed to a high point of perfection by several birds.

The weaver birds, which are at home in

TREE ROOFED IN BY BIRDS

COMMUNITY NESTS OF SOCIABLE WEAVER BIRDS OF SOUTH AFRICA

The thatched roof set in the branches of this tree was built from coarse Bushman's grass by hundreds of sociable weaver birds. First the foliage is eaten off the lower branches of the tree; then grass is brought to make the roof, on the under side of which each pair builds its nest. One generation after another will add to the structure, until in the end the tree sometimes gives way under the weight of the roof which it is carrying. Community life among insects, beasts, and birds is discussed in a later chapter, **"From Ant to Elephant."**

Africa, India, and the Malay Peninsula, take their name from their habit of weaving their nests in the same way that our Baltimore oriole does her weaving. Of the nest of the baya weaver, Dr. Jerdon has given an account so interesting that it is worth quoting at length. "Its long retort-shaped nest is familiar to all; and it is indeed a marvel of skill, as elegant in its form as substantial in its structure, and weather-proof against the downpour of a Malabar or Burmese monsoon. It is very often suspended from the fronds of some lofty palm tree. . . . In India I have never seen the baya suspend its nest except on trees; but in some parts of Burma, and more particularly in Rangoon, the bayas usually select the thatch of a bungalow to suspend their nests from, regardless of the inhabitants within. In the cantonment of Rangoon very many bungalows may be seen, with twenty, thirty, or more of these long nests hanging from the end of the thatched roof, and in one house in which I was an inmate a small colony commenced their labors toward the end of April; and in August, when I revisited that station, there were above one hundred nests attached all round the house!" A baya weaver's nest of the most perfect type "consists of a long suspension cord attached to a twig or palm frond, and holding up a bulb expanded on one side into a nesting chamber and prolonged downwards on the other into a long entrance spout, up which the bird darts. The young and eggs are kept from tumbling down the spout by a strong partition which separates the nest-cup from the spout, and, being built before either, serves as a perch for the bird working inside the dome." At the time when this partition is to be constructed, an interesting division of labor is made, the female taking her seat on the loop within, leaving the cock bird to bring materials and pass them in to her for the fine, inner work on the nest. It is the custom of the birds to put lumps of clay into the nest, probably to balance the swinging structure and prevent its being too much blown about by the wind.

BUILDING IN COLONIES

One species of weaver bird, probably the most celebrated, is the sociable weaver of South Africa, which collects in great numbers to make in the branches of a tree, from which the foliage has been eaten off, "a massed nest-foundation of grass" which serves as a roof, on the under side of which each pair builds its nest. The appearance of the tree is like that of a thatched roof, put together from the coarse Bushman's grass. This straw roof is often so heavy that the strong branches of the acacia tree in which the birds build may give way under the weight. The individual nests suspended below the roofs are woven of dry grass and joined together with the openings downward. Frequently from twenty to forty nests are hung under the same roof; sometimes there are hundreds. Le Vaillant mentions one colony of three hundred and twenty inhabited nests. Each year the birds build new houses under the old, thus adding to the weight sustained by the great straw roof. It would seem as if the phrase "dwelling under one rooftree" might well have originated here.

A BIRD THAT SEWS

Along with the weaver birds we must speak of the well-known tailor bird of India, a little warbler of about the size of a wren, "one of the most common — and noisiest — inhabitants of Indian gardens." "The wonderful little nest consists of a deep, soft cup enclosed in leaves, which the tailor bird sews together so as to form a perfect protecting sheath." The thread with which the bird sews is generally from cobwebs, but the cocoon silk of caterpillars is also likely to be used, or any vegetable fibers or bits of string which may be within reach. The needle is the bill, which is slender and sharp-pointed. With it the bird pierces the holes along the edges of the leaves, and then pushes the cobwebby thread through them and draws the sides together, making the appearance of stitches. This leaf-cup is very difficult to find, as there is nothing but the stitches to call attention to the way the leaves have been pulled a little out of their natural position on the tree, and stitches of spiders' webs are naturally far from conspicuous. Within this excellent protecting sheath the real nest is laid, made of fine cotton wool and vegetable fibers or horse-hair or some similar material. In this long leafy nest, which looks like a little pointed

bag or purse, three or four eggs can swing undisturbed.

Felting is another process of construction used for the hanging nests, scraps of dry leaf, fiber, and similar materials, being matted together into a tough felt by the webs of caterpillars and spiders. The resulting material is said to be so closely pressed together that it strongly resembles cloth. Sun birds, flower peckers, and tits, all tropical birds, practice this craft of felt making.

The southern countries have their bird masons, of which the most notable is the ovenbird of South America. Of the nest of this bird a traveler has written: "When we have passed the lofty mountain chains which divide the vast coast forests of Brazil from the plains of the campos, and descend the hills of the Rio das Velhas Valley, there on all sides one notices, in the great trees which stand solitary in the neighborhood of dwellings, large melon-shaped masses of earth on the stout, spreading branches. Their appearance is striking. . . . We soon find out what is the true nature of these heaps of earth; we recognize the large oval aperture at the side, and presently we may see going in and out a little bird with warm brown plumage: it is, in fact, a bird's nest — that of the ovenbird, known to every native by the name of 'Johnny Clay,' 'Jono de barro'." The ovenbird is a wonderful worker in mud; his domed nest is solid beyond any structure we have yet met in our examination of nests, its material consisting of mud and clay strengthened by a mixture of grass and vegetable fibers. Its construction is architecturally clever, as the entrance on the side does not open directly into the main chamber but into a roofed porch which is shut off by a firm partition reaching nearly to the top of the nest from the inner room where the eggs are laid. An unwelcome visitor would have a hard time forcing his way in. "When the structure is finished it looks rather like a small oven, and weighs about nine pounds." The nest is the more wonderful when we think what a little bird constructs it.

NESTS THAT ARE GOOD TO EAT

Some of the insects and many birds use saliva for gluing their nests, but it remains for one of the swifts of the tropics to make its nest entirely of dried saliva, the result being an edible composition which is esteemed highly by the Chinese as a table delicacy, made into "bird's-nest soup." These nests are attached to the face of cliffs or the walls of caves, the swifts colonizing for nesting so that the surface is covered with clusters of the little eggshell baskets, their flattened side fastened to the rocky surface. When we speak of "bird's-nest soup" there rises before our minds the picture of a stew made from the ordinary bird's nest of twigs and plaster. But these birds' nests are of a thin, white gelatin which is not uninviting and is said by Westerners as well as Orientals to be the basis of a very appetizing soup. The natives risk their lives getting the nests from the almost inaccessible cliffs along the coasts of the islands about Siam and the Malay Archipelago; but the industry is of such value that they pursue it in spite of its danger. One author tells us that it is customary for the natives to take the first nest of the season just before the eggs are to be laid. The little birds set to work at once to make another, and in this or a third nest they are permitted to lay their eggs, one nest a year being allowed them for the rearing of a family. The colonies are so thick and the nests so valuable that the harvest of a single year was valued at over one hundred thousand dollars and the weight of the product sold was said to be eighteen thousand pounds. When we consider the eggshell character of each nest, this is an immense total in weight.

BIRDS THAT BUILD INCUBATORS

There are in Australia two or three species of birds which erect mounds of dead leaves, grass, and other vegetable matter which will ultimately serve them as nests. The advantage of these mounds seems to be that the heat of the decaying vegetation acted upon by sunlight hatches the eggs. The bird is thus relieved of the labor of brooding over the eggs, as most birds do to keep them warm. These mounds are added to year by year until "they assume such large proportions that it is no uncommon thing to find the trees growing upon them as if they were hillocks of earth." One of these birds is called the mound bird, from its habit of

nest building. Gould tells of penetrating a dense thicket and coming upon a mound of gigantic proportions. "It was fifteen feet in height and sixty in circumference at the base, the upper part being about a third less, and was entirely composed of the richest description of light vegetable mold; on the top were very recent marks of birds' feet. The native and myself immediately set to work, and after an hour's extreme labor, rendered the more fatiguing from the excessive heat and the tormenting attacks of myriads of mosquitoes and sandflies, I succeeded in obtaining an egg from a depth of about five feet. . . . The holes in this mound commenced at the outer edge of the summit and ran down obliquely toward the center. . . . The mounds differ very much in their composition, form, and situation. . . . These mounds are doubtless the work of many years, and of many birds in succession; some of them are evidently very ancient, trees being often seen growing from their sides." Such structures as these are the parallels in bird world of our incubators, the heat being supplied either from the sun's rays, where they are constructed of sand and shells, or from the fermentation of the decaying vegetation which makes them natural hotbeds.

A BIRD THAT BUILDS PLAYGROUNDS

All the bird craftsmanship of which we have spoken thus far has been directly in the line of utility and in the course of necessary nursery building, its beauties being probably incidental to its main purpose. The bower bird of Australia goes a long step further. In addition to its regular nests, it builds bowers or runways, which are merely summer pleasure resorts, especially for the social dancing and posing of courtship days. One species builds its bowers in the branches of a tree. It first makes a broad, rather convex platform of sticks firmly interwoven. Upon the center of this platform a bower is built of more flexible twigs, and at or near the entrance to the bower are placed white or brightly colored shells, pebbles, bones, feathers, and rags. Another species builds long avenue-like bowers upon the ground, ornamenting the entrances in the same way. "But by far the most extraordinary bowers," writes Frank Finn, "are built by two species which favor flowers as decorations. . . . The gardener-bird . . . builds a conical hut round the stem of a sapling, and in front of it lays down a lawn of moss on which are laid flowers, buds, and gay-colored insects. As these decorations fade, they are thrown away at the back of the hut and replaced by fresh ones. . . . The habits of Newton's bower bird, though comparatively recently made known, are, if anything, more extraordinary. This species raises heaps of twigs round two adjacent tree-stems, a yard or so apart, adding to the piles year by year until they meet. In old houses one pile is always higher than another, and the higher one has been found three yards high — a good-sized edifice for a bird no longer than a thrush; this species being small for a bower bird. It is the higher pile or wall of the V-shaped arcade that the birds decorate with flowers, especially favoring white orchids and rock-lilies, while ferns and moss are also used. Quite a number of birds will frequent a large old bower, and they are quaintly touchy about having their decorations moved, so much so that the old males, who seem to be the artistic spirits of the community, will fight each other over the implied criticism of an altered decoration. Such a state of affairs seems to mark the limit attained by the evolution of bird social displays, and we may hail Newton's bower bird as the most highly evolved creature outside man in the matter of refined and intellectual amusement. . . . It is significant that the bower birds, with their wonderful habits, are confined to Australasia, a region where life seems to be more secure." With the struggle for existence less acute the feathered architect extends his range of activities beyond those of primal necessity; with food and shelter easily acquired he has leisure remaining for these other activities.

Photo by Wm. L. Finley and H. T. Bohlman

A RUFOUS HUMMING BIRD THRUSTING HIS BEAK INTO A GERANIUM BLOSSOM

NATURE'S TOOLS

The ingenuity of life, as shown in its tools—hooks, spears, saws, files, knives, chisels, barbs, probes, shears, fish nets, scissors.

SAWS and chisels, files, drills, forceps, probes, picks, shovels, rakes, scissors, hooks,—man may think that because he invented them for his own use they are his exclusive patents. But Nature, which made of its living creation a race of craftsmen, did not leave them unprovided with implements for their work. To each little creature was given the equipment which would enable him to accomplish his necessary tasks. If Nature were to assemble from all parts of the world the tools with which its workers are equipped, setting them up in a big exhibit, and man were to take from his tool chests the tools which he has made and lay them side by side with Nature's, there would be found an interesting and astonishing similarity. As we studied the work of insect craftsmen, we found the mason wasp using her jaws as trowels, the carpenter bee sawing and boring her way into the wood, and other insects using specially fashioned parts of their bodies as tools. Saws, drills, probes, and other cutting instruments are the chief tools found in the insect world. They are wonderful to us because though so small they are yet so effective. Only as the microscope magnifies them for us can we get any sense of their reality.

To the average person there is more interest in the tools of animals than of insects, because we can better understand and appreciate what the higher animals wish to accomplish and how their equipment enables them to do it. Take

Photo by R. W. Shufeldt

GEORGIA POCKET GOPHER

the mole for an example. He seeks to spend his life underground, and so must burrow and tunnel into the earth. (Underground life has been adopted, so nearly as we can judge, by many animals which could not have held their own amid the dangers and the competition of life on the exposed surface of the ground.) The mole has an equipment which no digger could better. He has a tough, pointed snout, strengthened by an extra bone, with which to probe his way into the ground, and a fore-paw which is shaped to serve as a powerful shovel, with a curved claw on the inside acting as a kind of sickle. Poking into, tearing away, and shoveling back the earth with snout, shovel-like paw, and claw, he digs his burrows with extraordinary speed. It is a careful naturalist, Hornaday, who is sponsor for the statement that a mole has been timed as digging one hundred and four and a half feet in twenty-four hours. The mole digs not only tunnels in which to travel and hunt, but also a protective labyrinth, with several approaches or runs, within which he makes a nest of grass or of leaves or of a combination of the two. The winding tunnels help him to make his escape from any approaching enemy. The entire structure is a marvelous piece of engineering and construction for a little creature which, outside of its environment, might be judged as slow, half-blind, and presumably rather stupid. This is another case of having chosen life in a certain zone and become so perfectly adapted to it as to be ill-fitted for life in that zone where mole life probably began, the surface of the earth.

THE POCKET GOPHER

Speaking of claws, we must look at those of this pocket gopher, who has so kindly held them out for us to observe. His remarkably strong feet serve like those of the mole as pick, shovel, and rake. Dr. Merriam, who has watched the pocket gophers, so familiar in our southern states, says that in making their excavations they first use their strong upper teeth as a pick to loosen the earth. "At the same time the fore feet are kept in active operation, both in digging and in pressing the earth back under the body, and the hind feet are also used in moving it still further backward. When a sufficient quantity has accumulated behind the animal, he immediately turns in the burrow, and by bringing the wrists together under the chin with the palm of the hands held vertically, forces himself along by the hind feet, pushing the earth out in front. When an opening in the tunnel is reached, the earth is discharged through it." The pocket gopher gets his name from the curious pouches or pockets, opening beside (not into) the mouth, in which he can store away a large amount of food, to be transported to his roomy underground home, there to be discharged and stored for future use. The mole and the gopher belong to the same big family as the squirrel. It would be an interesting study to trace the storing instinct in this family of rodents. The prairie dog is another familiar member of this group of digging animals.

TEETH AS TOOLS

Combination tools are Nature's specialty. No animal can be troubled to carry around with him a special set of tools for each new task to which he may set himself. Nature takes the simple apparatus of daily life — teeth, feet, tails, noses — and turns them to account. Teeth, in human activities, are associated with the taking

and chewing of food. For the lower animals they are in many cases more used as tools and weapons than in the actual preparation of food for the stomach. The teeth of the beaver are strong, sharp chisels, with which it can drive into a tree, making a deep incision all around the trunk, until at the last sharp strokes the tree topples over in the direction in which the beaver has intended it to go. (See illustration, Volume X, page 271.) When the tree has fallen, the next work is to cut it into pieces of a size which can be removed to the scene of hut-building. In the making of the hut, forepaws, teeth, and tail serve the purposes for which the human carpenter has his kit of tools, even to the mason's job of plastering with mud for strength and security.

The beaver is typical of many animals in its use of small, not extraordinary teeth for food getting and food preparation, and also for building operations. In some animals teeth are enlarged into tusks, projecting beyond the lips, as in the walrus, the boar, or the elephant. These tusks have a variety of tool-like uses.

Walrus tusks are formidable-looking, downward-turning instruments. They serve their owner as climbing hooks when he wishes to mount a slippery rock as he lifts his heavy body from the water, or as digging implements when he is hunting in the mud for food. And like all tusks they serve as very effective weapons. Boar's tusks turn upward. He carries his snout low for digging and uses his tusks to root into the earth and toss it up. The hippopotamus uses his teeth to chew food, but he finds them useful also for reaping grass or sugar cane, when his huge jaws need to be reënforced by their sharp points. (Look at the photograph of an open-mouthed hippopotamus, Volume III, page 204.)

ELEPHANT TUSKS AND TRUNK

No tusks in all the animal kingdom are more useful than those of the elephant, who, by the way, is in many particulars a remarkably well-equipped member of animal society. There are two distinct species of elephants, the African and the Indian. With the Indian elephant, which is the more docile and easily tamed, the male alone has the greatly developed tusks. This is the elephant that is exhibited in this country. In the African species, which is not often tamed, both males and females have enormous tusks, sometimes weighing one hundred and fifty to two hundred pounds.

In his fascinating book, "Animal Secrets Told," Mr. Brearley has given us an interesting study of the way in which tusks and trunk serve the elephant in his business of living. The tusks, he says, are sometimes four, five, six, eight, and ten feet long. Their value is in obtaining food, not in chewing it. There is the tender, juicy inner bark of trees to be sought as food, and there are roots to be plowed. The tusk has a good curve to give it purchase, and it is made of ivory, which is a most elastic substance. He reminds us that the ivory billiard ball will rebound with more elasticity even than the rubber ball.

But it is not the elephant's tusks alone which serve him as tools. His flexible trunk is a general utility instrument of rare efficiency. Cuvier once dissected a trunk and tried to count the muscles, but gave up the effort after counting

Shufeldt after Medland

MALE AFRICAN ELEPHANT

Sought by hunters for the valuable ivory of the tusks.

twenty thousand, estimating that there were at least double that number in the entire length of trunk. Such muscular development makes for extreme flexibility and for great strength and

control. The elephant is the largest of our existing mammals, a survivor of an age of giant animals. His life has been described as one continuous meal, for his huge body must be reenforced by several hundred pounds of food a day. With the aid of his long trunk he can choose food from the ground, from the tree top, or several feet to the right or left. He can tear off the huge limb of a tree, or pick up a bit of food as small as the coin which the trained elephant lifts from the ground so dexterously. Swimming he uses his trunk as a diver's air tube, thrusting the end above the surface of the water for air. When on land he can use it as pump and hose, lowering it into a stream, sucking in the water, then discharging it into his throat or spraying his back and sides. In his "Life-Histories of African Game Animals" Roosevelt writes interestingly of his observations of the elephant's use of his trunk. "By watching a herd of elephants," he says, "any one can speedily see the wide range of uses to which the trunk is put, and the many needs and emotions which it develops and satisfies. During courtship the bull and cow caress one another with their trunks. Elephants are very curious, and the trunks are used to test every object which arouses their curiosity. The cow is constantly fondling and guiding the calf with her trunk. The trunk is used to gather every species of food and to draw water. It is used to spurt dust or water over the body; it is used to test rotten and dangerous ground. It is in constant use to try the wind so as to guard against the approach of any foe. As one watches the great beasts the trunks continually appear in the air above them, uncurling, twisting, feeling each breath of air."

Drawing by Shufeldt

GIANT ANTEATER, OR ANT BEAR

With long narrow snout to poke into a huge anthill and long tongue to lick up the insects.

THE GIANT ANTEATER AND HIS SNOUT

The giant anteater, or ant bear, as he is sometimes called, has an extraordinarily long tubular snout to poke into the huge colony mounds of tropical ants after he has torn the mound apart with his claws. Within the snout is a long sticky tongue with which to lick up the insects as they swarm out of the nests. The small mouth opening and the tiny ears, when compared with the long snout and the huge waving tail, make him one of the most curious-looking creatures of the animal kingdom.

BIRDS' BEAKS

For variety and efficiency birds' beaks would probably take the prize in any competition, especially when it is remembered that all Nature has to work with in fashioning this set of instruments is two pieces of horn. What it can make of them in the way of variety of effect our pictures show. There are bills that are sharp and bills that are blunt, bills that are long and bills that are short, bills that curve up and bills that turn down, bills with hooks, bills with grooved edges like a saw, bills that are crossed, —and every bill serves exactly the purpose for which it is appointed and meets the food or craft needs of its possessor with a rare perfection. Some birds have a generalized style of beak which is good for a variety of uses. Of these the common crow is a good example. He has a varied diet of animal and vegetable items. He eats fruit, corn, and other grains, and an amazing variety of worms and insects. For the acquiring of these many items of his menu he makes use of his strong, handy little beak. Other birds — and they are the ones most interesting for our present study — have specialized beaks for particular kinds of need. Of these the woodpecker is a familiar type. His beak is a drill, sharp and very strong, shaped something like a wedge. With this he can pick up the

Photo by Wm. L. Finley

TUFTED PUFFIN

With brilliantly colored beak and soft yellow plumes over the eyes. (See also color plate facing page 168.)

Photo by Wm. L. Finley and H. T. Bohlman

AMERICAN OSPREY, OR FISH HAWK

With powerful hooked bill for tearing his prey.

grubs and insects which are his food; he can also drill into the wood.

The eagle catches his prey with his feet and uses his curved hook beak to tear the flesh. This beak is typical of many fish-eating birds, as the stout spear beak is especially suited to the capture of fish. Mr. Finley's remarkable photograph of a humming bird thrusting his long probe into a flower shows a perfect example of adaptation to food habits. The bill in some types is practically the same length as the bird's body and tail combined. There is no prettier sight than to see one of this species of humming bird flitting from flower to flower, burying his beak deep in the bell-shaped blossoms. To make such an instant permanent by catching it on the plate of a camera is an achievement for which we may all be grateful. (See page 163.)

THE BIRDS SHOWN IN THE COLOR PLATE

Dr. Shufeldt has pictured for us in his color page a group of typical and unusual bills from all over the world. Let us follow through their list and see the uses of some of these strange productions of Nature's art. The first (1) is the crossbill, a most curious and interesting type in which the ends of the bill cross each other, the lower one usually passing to the right of the upper one, with the tips arranged as shown in the figure. The crossbill is a small bird about the size of a bluebird. He feeds on the seeds of pine cones, and in order to get at these seeds inserts his bill between the scales of the cone, forcing them apart by opening the mouth, when the seed is adroitly extracted by the aid of the tongue. The king of the fly-catchers (2) is a tropical bird with conspicuous crest, the bill weak and much compressed from above downward. He is a good example of the birds which take their food on the wing. Our common kingbird also snaps up insects as he flies. Of the many hundreds of humming birds known to science, our artist has chosen to show us the head and bill of this beautiful Santa Marta humming bird (3).

The brown pelican (4) has a hook at the end of his long beak, and has also the lower bill modified to take the part of a rim for a bag or dip net with which he can scoop up fish. Next to him (5) is the curious, gigantic shoebill or whale-head stork, that feeds upon lizards, toads, and frogs, a wading bird that snaps them up, being aided by the hook on the upper bill. The ocellated turkey (6) is a gorgeous fellow, with a beak typical of wild and domesticated turkeys, who lives in Honduras, Yucatan, and Guatemala. Right in the center of the plate (7) is the charming little spoonbill sandpiper, his bill flattened out in such a way that it seems to be especially well-fitted to take up food along the beach and separate it from the sand before swallowing it. Why this particular sandpiper, however, has this type of bill when scores of other sandpipers do not, it is difficult to say. Our American spoonbill, a bird as large as a small heron, has a similar bill. To the left and to the right of him are the rhinoceros hornbill (8) and the ariel toucan (9), examples of the tropical hornbills and toucans with their immense bills of different forms. Internally these structures are of a spongy nature, and consequently of wonderfully light weight. Toucans' bills are often very highly colored, in yellow, red, blue, green, and black, making the birds very conspicuous. Hornbills carry, as their name indicates, an extraordinary added structure at the rear end of the bill, for which there seems no use beyond affording an added surface for high coloring. As toucans and hornbills are great fruit eaters, their big bills afford the required extensive surface for crushing such morsels as ripe figs preparatory to swallowing them.

The macaw (10) is a representative of the parrot and cockatoo groups. He feeds principally upon nuts, fruits, and seeds; and to crack, crush, or open such foods, a heavy, powerful beak is quite essential. Many of them employ their great hooked bills in climbing among the limbs of trees. The puffin (11) has a curious wedge-shaped beak, very different from that of many fish eaters, and noticeable for its high coloring and for its size compared to the rest of the body. Most surprising of all, part of this bill is regularly shed at the close of the nesting season, the covering of the red tip and the green base being slipped off, so that its winter appearance is very different from its summer one. And last of all (12) comes the flamingo, with his bill bent at an angle in the middle to aid him in his particular mode of food getting.

VARIETY IN BIRDS' BEAKS

BEAKS AND BILLS AS NATURE'S TOOLS

Starting at the top and following from left to right, we have in the top row the crossbill (1), the king of the flycatchers (2), the Santa Marta humming bird (3); in the second row, the brown pelican (4), the shoebill (5), the ocellated turkey (6). In the center of the plate is the little spoonbill sandpiper (7); below at the left the rhinoceros hornbill with a red horn on his yellow beak (8), and opposite him at the right the ariel toucan (9). In the bottom row are the macaw (10), the puffin (11), and the flamingo, with his curious bent yellow beak (12).

BIRDS THAT FISH

The flamingo has a very long and slender neck and long legs. He lives upon small water creatures, wading into the water to feed. As he stands he treads up and down to loosen the mud, then bends over for the mollusks, crustaceans, or vegetable matter of his desire, scooping in his mouthful. In feeding, says Steyneger, he reverses the usual position of the head until the bent portion of the bill is parallel with the surface of the ground, thus working backward instead of forward. One writer has compared this bent bill to a potato masher, the mud being forced out through the little side-strainers until the food is washed clean and is ready to swallow.

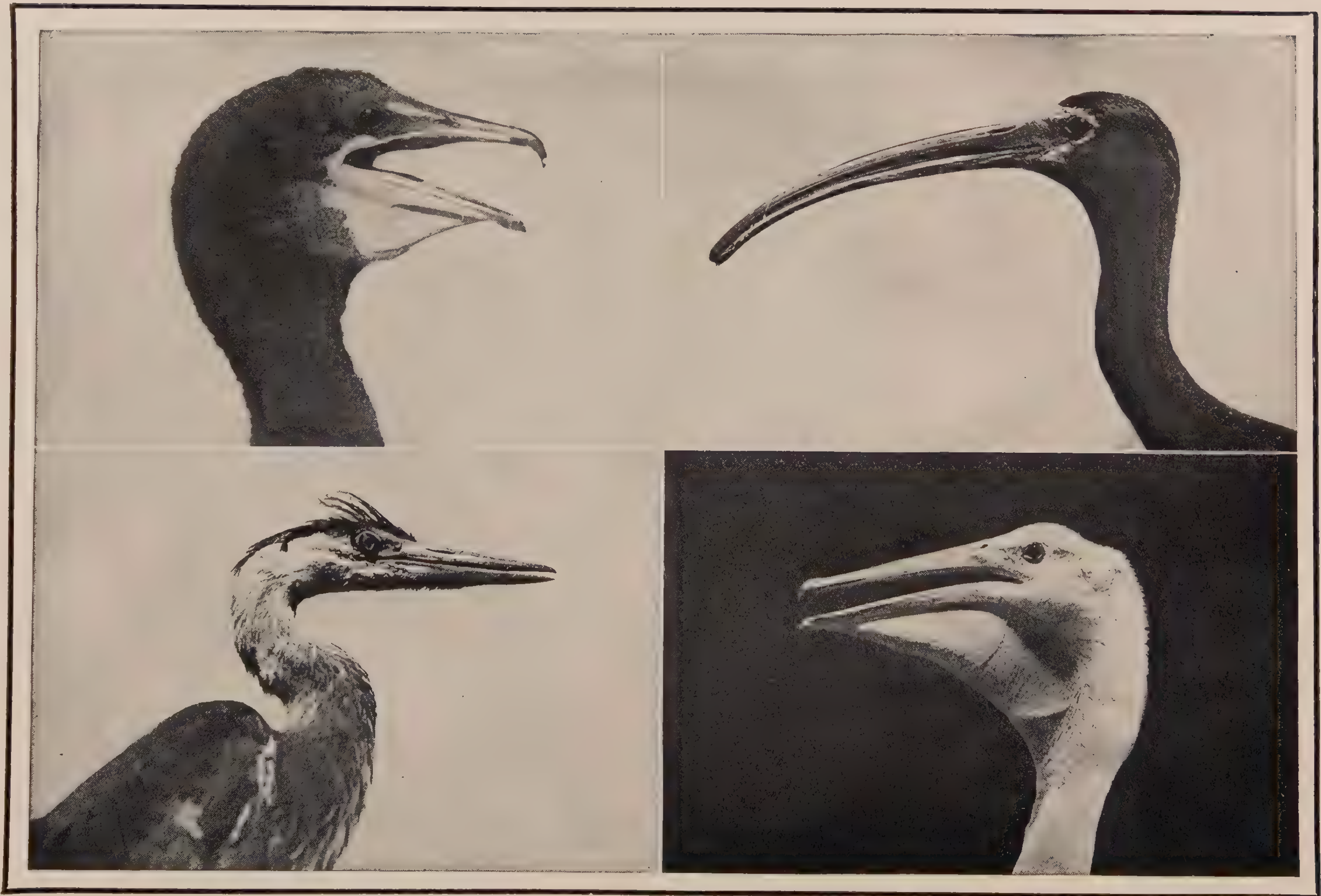
Mr. Finley has shown us the white pelican in many attitudes and locations. The most marked characteristic is the pouch which depends from the lower bill, forming a real scoop net. When the pelican is ashore this hangs like an empty pocket. When he is out for food, among the schools of fish which swim near the surface, he dives into the water, open-mouthed, the sides of his pouch spread out, and scoops them in. Then he must drain out the water he has swallowed and gulp down the fish; both operations he performs quickly and skillfully.

The great blue heron has another and more common way of fishing. He fishes in the early morning and in the evening, wading into the water and standing quietly watching until he sees his prey; then seizes it by a swift stroke of his long pointed bill and swallows it head downward. The kingfisher throws himself into the water, using his sharp beak as skillfully as an archer would use an arrow to pierce his fish. One bird has a down-curving bill, another an

Photo by L. W. Brownell

FLAMINGOES — BIRDS ON STILTS WITH CURIOUS BENT BILLS

For the colors of these beautiful, graceful birds, see frontispiece, Volume III.



Photos by Wm. L. Finley and H. T. Bohlman

BIRD PORTRAITS

Top (left), young cormorant; (right) white-faced glossy ibis. Bottom (left), young great blue heron; (right) white pelican, half grown.

up-curving; and so we might go on, with the skimmer's bill, which works like scissors blades, cutting the water, the insect-taking birds with their rows of bristles which serve as the meshes of a butterfly net to strain the air as they fly about open-mouthed, and many another curious

Photo by Wm. L. Finley and H. T. Bohlman

PELICAN YAWNING

contrivance. But pictures tell the story better than words, and with them both the point is surely proved that Nature's exhibit of tools is unique and remarkable.

THE GREATER MARVEL

If, as we pass along in our story, the question occurs to us as to what is the significance of the frequent parallels between man and Nature, we shall have learned to put these wonderful signs of Nature's skill in equipping its creation as signs of a greater marvel, — the marvel of the unity of all life. We have seen how similar are the problems of all living things, whether they walk or creep or swim or fly. All must get their living; all must pass on their life to new generations. In the business of food getting and nursery building most of the higher animals are engaged for a good part of their active hours. Nature is endlessly fertile in devices. It is not surprising that for each animal there has been, and is being, worked out the best equipment for

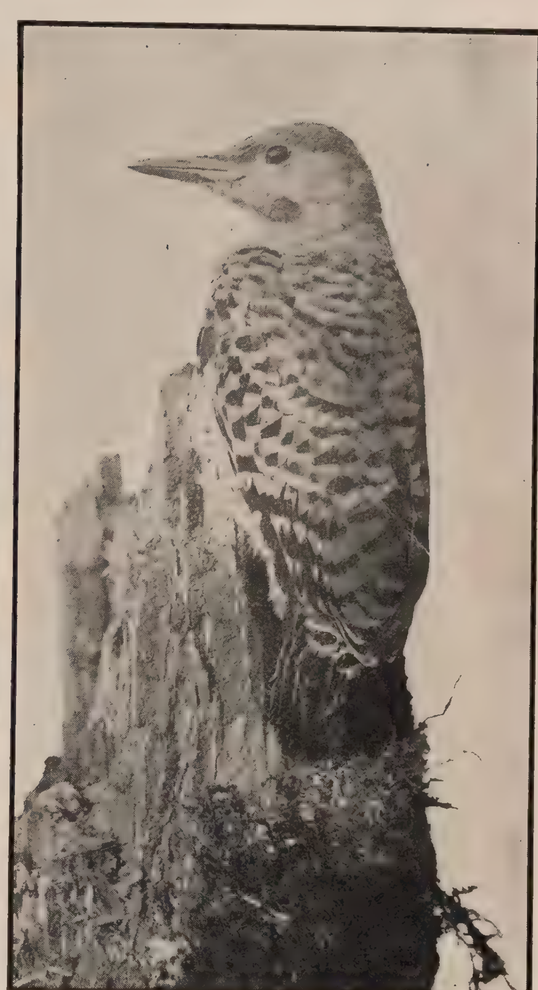


Photo by Wm. L. Finley

RED-SHAFTED FLICKER

his particular task. Nature's workshop is at our doors; its work is going on under our very eyes. That man, with only his hands for tools but with the wide world to draw on for materials, has worked out similar devices to meet similar needs, is a sign of his wonderful creative power. Mind in Nature, working slowly up the ladder of life, finds its climax in and is also paralleled by mind in man, who is the creator and inventor. We are approaching these counterparts with the key to their meaning when we look at them as signs of the wonderful unity of all life.

Shufeldt after H. H. ter Meer

PORTRAIT OF WALRUS

Walrus tusks are powerful instruments in peace or war. They serve their owner as climbing hooks when he wishes to lift his heavy body from the water to a slippery rock, as digging implements when he is hunting in the mud for food, and as formidable weapons of offense and defense. The walrus is a very large marine animal of the Arctic Ocean. The male has these very large downward-turning ivory tusks, the female smaller, slenderer tusks. A walrus often weighs over a ton.

Photo by R. W. Shufeldt

LEFT FOOT OF MONKEY-EATING EAGLE

NATURE'S WEAPONS

The battle of life, as it is carried on with spears, arrows, stings, and whip-lashes, with poisoned weapons, with poison gas, with bombs, behind smoke screens, by means of electric shocks.

THE line between a tool and a weapon is easily overstepped, with no change in the article in question but only a different intention in the hands of the user. A hatchet is a tool in the hands of a woodchopper; in the hands of a would-be murderer—even of the woodchopper himself in a murderous mood or in a dangerous plight — it may become a weapon of offense or defense. With Nature this double use of a single instrument is far more common than with man, — first, because Nature must be economical of its products, and next, because Nature's kingdom is one long battle line. The business of living keeps most creatures on the offensive or the defensive. Before we leave the subject of tusks and claws, beaks and bills, we should remember that each one of these instruments is frequently a weapon, and is as effective for this use as it is for more peaceful purposes. Nor does the story of Nature's offensive and defensive contrivances end here. The use of bombs, poison gas, and smoke screens illustrates the more subtle devices which we shall find if we take the term "weapon" in its broad as well as its narrow sense.

The weapons of offense of the larger birds and animals of prey are the most conspicuous examples of the double use of a part of the body in peace and war. The foot of the monkey-eating eagle, shown at a little less than natural size at the head of the page, is a formidable instrument for catching and tearing the prey, which, with the help of the hooked beak, the eagle will kill and devour. Not only is this foot equipped with sharp, long claws; its muscular control is also such that with it the eagle can get and keep a very powerful grip. The strength of many of these ferocious birds of prey is enormous. They can catch and kill an animal much larger than themselves and carry it off with them. To attempt a catalogue of weapons of offense would be to swing from the

tusks of the walrus, long, strong, and sharp, to the branched horns of the moose; from the claws of the crab to the snakelike arms and the suckers of the death-dealing octopus; from the sting of the bee to the whiplike tail of the sting ray. The range of means of defense would cover as wide a field, going from the spines of the porcupine to the electric battery of the torpedo; from the odorous fluid of the skunk to the inky discharge of the squid. Over and above the interest in each peculiar and effective device will be the interest in Nature's clever manipulation of its simple resources. Nature does not go out of its way to create special offensive or defensive parts for its creatures. It takes a usual and familiar part and turns it, by some simple means, into a protective or aggressive contrivance. If there is any lesson we are to learn from Nature in its creative operations, it is not to go far afield in search of some wonderful and extraordinary materials but to fashion the object of our need or our desire from what we have at hand.

SPINES AND QUILLS

We have seen how skin developed into hair for protection from cold, wet, and other external conditions. The hedgehog and the porcupine show how ordinary hairs were developed, at need, into sharp, barbed spines. That is a transformation which would not have occurred to us, but how well it works! When the quills of the porcupine lie flat among the coarse hairs, they are not over-conspicuous. But let their possessor be disturbed and they stand up all over the body in a way that makes the wise aggressor cease his attack and retire hastily while the "going is good." As if to show us by a set of living specimens, says Dr. Lydekker, how

Photo by L. W. Brownell

PORCUPINE EATING ROOT

In the porcupine, hairs have developed into sharp, barbed quills, providing him with an excellent defensive armor.

the change from hair to spines was accomplished, there are in the animal world individual creatures with every grade of hair and quills, from the spiny mice of North Africa with their stiff bristling coats to the tree porcupines, and finally to our own porcupine with his quill armor.

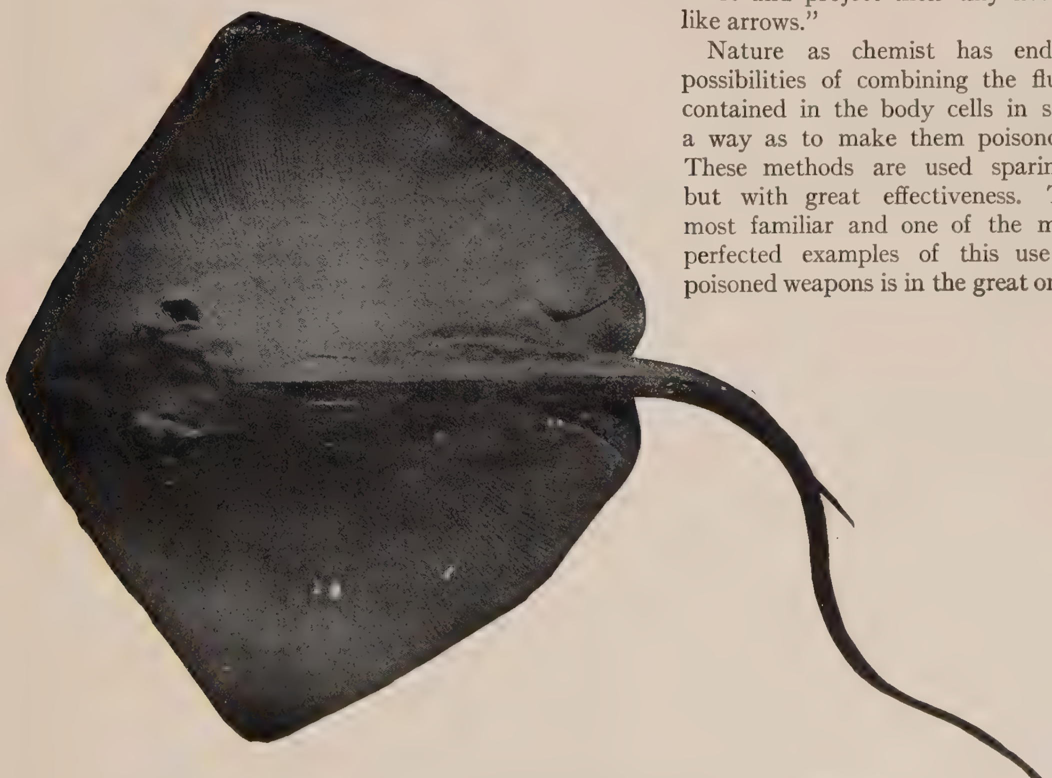
TAILS AS WEAPONS

Tails have been developed into weapons in almost every class of the animal kingdom. The sting ray's long tail is "provided with one or more large, stiff, barbed spines, used with great force by the animal." Some naturalists have thought there was a specific poison in the tail, but Jordan comments that no evidence has been produced as yet to prove this. A look at the tail, as shown in our photograph, will show us that without any poison its use as a whiplash would inflict severe punishment on the creature attacked. The scorpion's tail has a venomous gland with which it can inflict a severe sting.

POISONED WEAPONS

A whole army of creatures of many kinds, in the sea, on the ground, and in the air, possess the power to sting their neighbors either in offense, when they desire food, or defense, when they are desired for food purposes. A sting, says Webster, is any one of "various sharp organs of offense and defense, especially when connected with a poison gland or otherwise adapted to wound by piercing and inoculating a poisonous secretion." That is, where a sting is inflicted, there is usually a poisoned as well as a sharp weapon. From the simple polyp of which we read in Volume I (page 221) up through a large group of sea creatures there is in almost every individual a stinging apparatus, either of the lasso type there described or of the arrow type. One writer speaks of the power of striking the enemy "by a sort of poisoned dart thrown from irritating capsules developed in their tissues. At least contact these capsules burst and project their tiny needle-like arrows."

Nature as chemist has endless possibilities of combining the fluids contained in the body cells in such a way as to make them poisonous. These methods are used sparingly but with great effectiveness. The most familiar and one of the most perfected examples of this use of poisoned weapons is in the great order



Courtesy of American Museum of Natural History

STING RAY WITH WHIPLASH TAIL

of insects to which bees and wasps belong. All these sting-bearing insects "have a very efficacious weapon in the envenomed stiletto which they can project . . . at will. This sting is an instrument of the most delicate precision. Two valves protect it, united into a single piece whose lower side is indented by a channel in which rest the two 'bristles,' constituting the actual sting. This keen and effective little tool is supplied, from two glands in the body of the insect, with a venom consisting essentially of formic acid and of an alkaline liquid, the mixture of the two being necessary to inflict the injury." Of the sting of a bee Duncan says, "As the bee thrusts her dart into a victim the poison flows along a channel between the needles and the director, drenching the blades with the fluid, rendering this three-bladed sword the most deadly of insect weapons."

POISON GAS

Many beetles, as well as other insects, have the power of throwing out a fluid with a most unpleasant odor, which seems to serve as an excellent means of self-defense, the hostile creature retiring hastily before it. The little bombardier beetle is described as going through an operation which might, in the light of our own experience of warfare, be likened to the discharge of a bomb containing poison gas. There are many accounts from British eyewitnesses of this little creature, from which the following is compiled. It is a little fellow, but is pursued by a much larger beetle, against which it would seem as if it had little chance. At the moment in the pursuit when the bombardier beetle seems to be fleeing and on the point of capture from the rear, there is suddenly a loud "pop," as from an explosion. It is accompanied by a puff of smoke and an unpleasant odor. If necessary this is repeated again and again. The larger beetle in pursuit receiving this gas and odor in his face, accompanied by what is to him doubtless a terrifying and most surprising noise, acts stupefied, and, as if blinded, either retreats or delays so long in his pursuit as to let the bombardier beetle get away. What has happened is this. The bombardier has in the rear of his body glands which hold acid and serve as a tiny cannon or pistol. By a muscular movement he controls these glands and discharges when he wishes a drop of liquid having a strong acid reaction which explodes like a bomb on contact with the air, turning into a bluish vapor. The bombardier can fire his bombs a dozen or even twenty times in succession if necessary.

We recite the story of a device like this, and in a succession of accomplishments it is one more. But it is well to stop a moment and consider it. "Millions of years," says an English philosopher, "before men could write, paper was being made by wasps, and ages before men had discovered fire and explosives there was a little creature deluding its enemies with a sort of smoke barrage, and frightening them with reports which must have sounded, in the insect world, like heavy ordnance. Imagine a carnivorous creature attacking a bombardier beetle; pop goes the mimic gun, and up comes a cloud of smoke, while bombardier scurries mightily to his little dugout. Instinct enables the bombardier to ply his elusive art, but think of the magical development of structure which enables him to save his life by such a wonderful device. When you first pick up a click beetle, and he clicks in your fingers, the effect is so astonishing that you are almost sure to let go, though the little thing is quite harmless. . . . The click, the bang, and the discharge of vapor are all automatic now, fixed by ages of experience, but that does not detract from their wonder. They serve their purpose as well as a sting or a bite."

THE SQUID'S SMOKE SCREEN

The squid is another creature whose methods man has paralleled in the tactics of his warfare. In the Great War, airships, battleships, and moving armies resorted to the barrage or the smoke screen, under cover of which they might advance or retreat in safety. The squid has always practiced this scheme. He carries with him a convenient "ink bag," from which he can discharge a fluid which will so darken the water for a considerable distance that he can make his escape undetected. When he sees a foe approaching, he throws out his screen; if he is caught by a man or is fighting with a fish enemy, he can direct this fluid into the face of the aggressor, making the skin burn and smart. It is

THE SQUID'S "SMOKE SCREEN" COMPARED WITH MAN'S

said that "in captivity the creature will, in a few seconds, darken a thousand gallons of water so that its own whereabouts is completely hidden."

Other sea creatures have a water siphon in their bodies, which they use to good purpose when attacked or attacking, and the archer fish,

as you will remember, shows himself an expert sharpshooter, ejecting a column of water from his mouth and bringing down his victim, it is said, at a distance of from three to five feet.

FISH THAT GIVE ELECTRIC SHOCKS

The conscious use of electric power is so comparatively recent with us, dating back no further than the days of Benjamin Franklin and his contemporaries, that it is astonishing to find fish of the sea which are living batteries and whose ancestors were giving the fishermen who caught them powerful electric shocks before their captors knew of the existence of electricity. It is a marvelous method of offensive and defensive warfare which Nature has put into the possession of these two or three kinds of fish. They actually have the power to produce in their own organs and voluntarily discharge electricity in sufficient force to shock, or even kill, animals of much larger size than themselves. The electric eel possesses two pairs of organs which have all the properties of an electric battery, each organ containing two hundred and fifty or more cells. As this eel is often six feet long, the possession of this ability to give electric shocks makes it a formidable enemy. The torpedo is another big fish which can generate electricity. M. Arsonval, making experiments to measure the intensity of the electricity generated by a moderate-sized individual, found it was capable of producing at will a current varying from two to ten amperes, with an electrometric force of from fifteen to twenty volts. To the electrician these figures tell their own story; to the reader who is more familiar with electricity in terms of the light it produces than by its own units of measurement, it will be more intelligible to say that in these experiments a lamp of fair intensity (10 candle power), connected with the electric organs of the fish, gave out a bright flash of light as often as the animal was irritated. So far as any one has yet gone in the study of these electric organs, they prove to be developed from muscular substance and the action seems to be in its nature like muscular action. The power to inflict shocks is soon exhausted, and does not return until the fish has had rest and food. In the torpedo, with which the experiments above mentioned were made, the stomach and back of the fish were charged with opposite forms of electricity, and the shock was felt whenever the connection was made between the two. Another electric fish, the electric eel of South America, has the batteries located along the sides of the body in bands or columns running nearly four-fifths the length of the fish body.

"The electric catfish, a native of Africa," writes Pycraft, "is only a little inferior in its powers to the electric eel. . . . Kept in an aquarium with other fishes, it soon kills its companions. Unlike all other electric fishes, its battery is formed by a transformation of the skin, and not of the muscles. It envelops the whole body like a mantle between the skin and the muscles." It is a curious fact that the natives seem to recognize the connection between the shock inflicted by this fish and the shock from lightning, for they have called this fish "Raad," an Arabic name meaning "thunder."

THE FISHERMAN FISH, A LIVING FISHHOOK

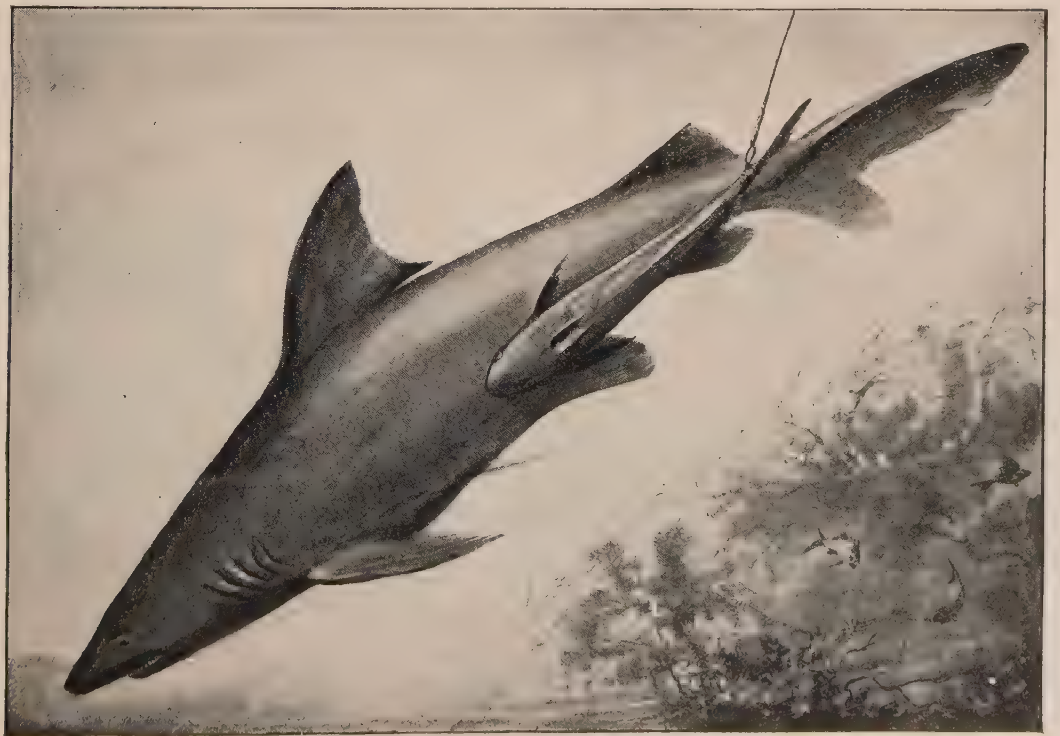
In *The American Naturalist* Professor Gudger of the American Museum of Natural History has collected and presented a most interesting body of information about a strange fisherman fish, the remora, observed in tropical or semitropical waters in our own day, and equally observed and commented on by Columbus and other early voyagers. This fish has a sucking disk by means of which it attaches itself to much larger fish with so firm a hold that they are unable to shake it off and must resign themselves to its parasite presence. A double interest attaches to it, both from its own powers and the use made of these powers by the natives of lands bordering on the waters which it inhabits. They have made of it a true fisherman by harnessing it and sending it out to attach itself to its prey, then drawing in the line by which it is held or following the line and thus locating and capturing its prey. A brief summary of Professor Gudger's articles will tell both the present story and the past history of this remarkable fish.

In 1884 Mr. Holmwood, British Consul at Zanzibar, brought to the attention of the scientific world the native's use of this fish. On one of his trips he had his notice called to a number of remoras attached to the sides and bottom of

a boat. He likewise saw natives digging out toy canoes far too small for any man's use and was told by his servant that they were for the sucking fish which were kept by most fishermen in their homes. He visited huts and found these fish from two to four or five feet long, and weighing from two to eight pounds, kept in the little water-filled canoes in the cabins and so tame that they would readily come to the surface at the appearance of their masters. Each fish had a strong iron ring or loop fixed just above the tail, to which was riveted a small movable ring or loop, resembling that of a watch. At first the account of these tamed sucking fish was laughed at as a myth, but it has since been confirmed, both from writings of other centuries and reports of to-day. Frank T. Bullen tells of Chinese fishermen who use the sucking fish to catch turtle, putting them out and then when they have attached themselves to the turtle pulling both in together. Professor Haddon, leader of the Cambridge University Anthropological Expedition to Torres Straits in 1898, tells of fish harnessed not only by a tail

FISH CHAINED BY TAIL

SHOWING SUCKING DISK



SUCKING FISH ATTACHING ITSELF TO AND CAPTURING SHARK

line but also with a short piece of string passed as a sort of bridle through the mouth and out at the gills. By means of these two strings the fish was held while slung over the sides of the canoe into the water. When the prey was sighted (in this case a turtle, but often in other accounts a shark) the short piece of rope was pulled out of the mouth of the fish, so that he would be free to attach himself by his sucking disk, and the tail line was let out with plenty of slack. The fish would dart instantly to the turtle and fasten himself to him. One of the crew would dive overboard, and, guided by the line, capture the turtle, man and turtle being taken into the boat again, while the sucking fish was made with difficulty to give up his relentless grip.

SUCKING FISH SEEN BY COLUMBUS

These accounts show that aborigines are at the present time using this fish as a living fish-hook in these waters about Torres Straits. In our own southern waters it is not uncommon to find remoras attached to sharks. And most interesting of all is the fact that in the accounts by Peter Martyr of the second voyage of Columbus to the New World in 1494 there is a similar story of this fish, so quaint and vivid in its language that it is well worth reproducing here:

"Now shall you hear of a new kind of fishing. Like as we with greyhounds do hunt hares, in the plain fields, so do they as it were with a hunting fish take other fishes. This fish was of shape or form unknown unto us; but the body thereof, not much unlike a great eel; having on the hinder part of the head a very tough skin, like unto a bag or purse. This fish is tied by the side of the boat with a cord let down far into the water. When they espy any great fish or tortoise, they let the cord at length. But when she feeleth herself loosed, she envadeth the fish or tortoise as swiftly as an arrow. And where she hath once fastened the hold she casteth the purse of skin whereof we spoke before, and by drawing the same together, so graspeth her prey that no man's strength is sufficient to unloose the same, except by little and little drawing the line, she be lifted somewhat above the brim of the water."

With this story we close our account of the many tools, weapons, and skillful devices with which animals are equipped for the business and battle of life. The struggle for existence is keen and taxes every creature to the limit of its powers.

Photo by Wm. L. Finley and H. T. Bohlman

CASPIAN TERNS FIGHTING

THE PHOTOGRAPHER PHOTOGRAPHED — MR. FINLEY TAKING PICTURES

In the picture at the left Mr. Finley is in a tree top in a heron colony. See the heron standing almost at his elbow. In the other picture Mr. Finley is at the right, Mr. Bohlman at the left. They are "corralling the baby duck (in the foreground) to get a picture, a process," as Mr. Finley writes. "that took about two hours of sloshing through the marsh."

Photo by Wm. L. and Irene Finley

COUGAR KITTENS

THE FIVE SENSES—AND OTHERS

The individual life—how each creature makes its contact with the world about it through the channels of the senses, how its world is big or little according to its powers.

THE senses are the channels through which any single life comes into touch with the world about it. We start with life in a cell, life active but imprisoned in its own package of protoplasm. When the single-celled creature, the amœba, makes use through its entire outer surface of a sense of touch and absorbs into itself its necessary food, it has made a contact with the world in which it exists. The more kinds of contact a creature develops, the more it really *lives* in the world about it. As we follow life up the scale of development, it is fascinating to see how through the growth and perfecting of eyes and ears and noses and tongues and feelers the world gets bigger and more varied for the individual creature. Without the senses each creature would live in a lonely, separate world. As the earth revolves on its track through space, so a little package of living protoplasm enclosed in a skin might wander about in its little track without the slightest recognition of any other creature. Many tiny water and land animals come very near to doing this now. But they are not left absolutely shut off from the world about them. The life within reaches out to the world beyond itself; the world without presses in upon this little separate living creature. And it is through the sense organs, and by the use of what we call the senses, that this contact comes. If there were no life within, the sense organs would be useless. Of what value an eye without a nerve to carry the story of what that eye sees, and a living something — call it mind, consciousness, what you will — to take the message and act on it! When we think of the senses, we should think of them as bringing together the world without and the life within.

Following close on this thought comes another, equally illuminating, that the world of each creature of the lower orders of life is as big as its senses report it to be. Dr. Longley went down into Fish World and spent hours there, entering into the experience of a fish. But he took with him not only the mental equipment, but also the sense organs of a man, not a fish.

Would a fish see as he saw, would it hear as he heard, would the touch of water upon its scales be as the touch upon his skin? These are questions to which even a close study of the sense organs of the fish, both by tests of living fish and by analysis with the microscope, can furnish but partial answers. Only as the senses report the world, does the creature "sense" or know it; only according to the degree of development of its sense organs — eyes, ears, feelers — can the creature "sense" its world. So the world is to each creature, little or big, what its sense organs are able to convey in the way of sensations and its mind to grasp in the way of impressions.

Each creature, to go one step further along this line of thought, has its own world in which it lives. The bounds of this world of its habitation are those to which it has traveled or to which its powers of sight, hearing, and other senses reach; the color, shape, and other characteristics of this world are those which its organs enable it to "sense." When we study the senses and sense organs of birds, beasts, and fishes, we are studying more than their physical make-up. We have gone beyond the mere structure — the claws and beaks and bills, the tools and weapons; we have stepped over the border line into the region where mind plays a part. As a creature's sense organ, so its sense; as its senses, so its conscious relation to the world about it: or, to start from the other side, as its mind, so its senses and sense organs, developed for the service of that mind.

As we study the powers of sight and hearing of the lower creatures, we are becoming more able intelligently to put ourselves in their places. Only by imagination, and only imperfectly, can we ever expect to enter into the mind of a bird, to see as it sees, to hear as it hears, and so in a measure to think as it thinks. But to go even a step upon that track is to go outside our own world into another world. With what science is now able to tell us of the sense organs and the senses of the lower orders of animals, we can for the first time intelligently take that first step into other worlds than our own. When we have done it, we shall doubtless step the more gladly back into our own. But if, besides the interest of a new point of view, we have an added appreciation of our own endowments, will not the experience have been worth while?

IN OTHER WORDS

"Our human world is a very limited part of nature. The unaided senses of primitive man open a few doors of communication between the individual and his surroundings, through which the sum total of his knowledge of things as they are must be derived. Science has greatly enlarged the efficiency of the natural sense organs — the microscope and the telescope have extended the range of vision, the periscope enables us to see around a corner, the spectroscope, photographic plate, X-ray machine, and innumerable other aids have enabled us to see deeper into nature. But no new senses have been developed and our furthest scientific advances and most recondite philosophical theories must be based in last analysis on such fragmentary knowledge of the cosmos as is revealed to us by our senses. Great realms of nature remain wholly unexplored, although new artificial aids permit constant advances into the hitherto unknown — Hertzian waves and wireless telegraphy, ions and the new chemistry, electrons and the new physics.

"Fortunately the traditional five senses do not represent our whole physiological equipment for this task. In fact, the human animal is endowed with about twenty distinct senses, including two in the ear, at least four in the skin, and numerous others in the deep tissues, such as muscle sense, hunger, thirst, and other visceral senses.

"It is well known that fishes and other lower vertebrates possess numerous types of sense organs quite unlike anything in our own bodies, and it is quite impossible for us to form any conception of what the world appears like to these animals except in so far as their sensory equipment is similar to our own. Even the companionable dog, who responds so sympathetically and intelligently to our moods, lives in a very different world. Recent experiments have shown that his sense of vision is very imperfect, especially for details of form, and everybody knows the inconceivable delicacy of the hound's sense of smell. With us vision is the dominant sense and our mental imagery is largely in terms of things seen. Even a blind man will say, 'I see how it is,' when he comprehends a demonstration.

"What sort of a world is it to a dog, whose finest experiences and chief interests are in terms of odors? And how does it feel to be a catfish, provided not only with large olfactory organs whose central nervous centers make up almost all of the cerebral hemispheres of the brain but also with innumerable taste buds all over the mucous lining of the mouth and gills and freely distributed over the entire outer skin from the barblets ('feelers') around the mouth to the tail fin? We cannot conceive the epicurean delights which such an animal may feel when he swims into the water surrounding a juicy piece of fresh meat, by whose odorous and savory juices he is bathed. One wonders, parenthetically, how far the fish himself is able to conceive or even enjoy the pleasures of life. With how much mind of any sort the fish is endowed is at present an unsolved riddle; but it is certain that his behavior complex is of very different pattern from ours and whatever mind he may have would surely be as different as the pattern of his sense experience is different." — C. JUDSON HERRICK.*

*From article on "The Senses of Fishes," in *Natural History*, Vol. XIX, 3, published by American Museum of Natural History, New York.

Photo by Wm. L. Finley and H. T. Bohlman

DOWNY GOLDEN EAGLES WITH DEEP-SET EYES

IN NATURE'S EYE FACTORY

Of the curving skin window of the snake which is shed and replaced once a year, of insects with a thousand eyes in one, of a four-eyed fish with near and far sight, of a shrimp with eyes on his fingers, of a flounder with an eye that travels, of a cross-eyed chameleon, of birds with marvelous eyesight, of creatures with eyes that shine at night, and of cave and deep-sea fishes with big eyes or no eyes at all.

THE story of eyes is one of the most fascinating life stories. There is more variety in the kinds of eyes with which Nature has endowed her living family than in almost any other organ. From the heat-sensitive pigment of the lowest creatures to the highly elaborated optical instrument of man is as long a step in mechanical development as Nature has ever taken. In the eyes of creatures all along the way up the ladder of life we can see the different steps in the process of perfecting eye machines.

HOW EYES CAME TO BE

Life within a creature, pushing out, and light without, pushing in — that was the situation that called into being Nature's eye factory. To realize why eyes came into existence, we have only to try to picture a world of blind creatures. Suppose a whole kingdom of living animals had been left to move about in a world bathed with light, to eat food created by light's energy working through the magic of the green leaf, to be warmed and given the power to grow through the agency of light, — and yet had never been able to see! The idea is inconceivable. Given life and light as two forces acting in the world, and eyes had to be. The brain within the creature had to reach out and find the light without; the light, acting on sensitive tissue, had to work in and find, within the living creature, something that would give back a response. What these two forces developed in the way of eye machines, how the animal kingdom passed from blindness to vision, is one of the great life stories of Nature.

THE FIRST EYES — WINDOWS

The first eyes which we see in Nature's factory would hardly seem to us to be eyes at all. They have no lenses, no pupil, no retina;

they are like windows, and very dull windows at that.

When Nature turned attention to eye making it did not set up a wholly new material out of which to fashion eyes. Nature is too economical and too ingenious for any such extravagant methods. It took something it had at hand and turned it to this new use. It had been wrapping up precious life packages in a covering of skin. Now it opened skin up in certain places, changed its texture and made it thinner, so that instead of shutting light out it would let light in. Skin, as the scientist puts it, became *translucent*, which is to say "letting light shine through." From a curtain skin was changed into a window.

Perhaps sight for a fish began something in this way. It came on a sensitive skin surface which dimly felt the difference between light and darkness. Perhaps his upper side "felt" the light and became increasingly sensitive. Then gradually certain nerves had their sensitiveness increased; gradually they located in a certain convenient spot; then came the skin window.

The first skin windows, possessed by the lowest forms of living creatures, are very thick and cloudy. In the next higher creatures they begin to clear themselves, until farther up the scale they become, not merely translucent, but transparent. The process is not unlike that which can be observed in the gradual development of windows in houses, from the thick skin windows in the huts of our earliest forefathers through windows of mica, paper, and opaque glass to our own transparent glass.

But a window is not a complete eye machine. Of what use is a window in the body of a creature if the creature does not know it is there, or has no power to use it? Here comes the other side of the story. Not only light pushing in, but life pushing out. The brain, at first hardly more than a sensitive nerve, pushed out to seek the outside world. The eye in the lowliest forms of life is only a bit of pigment connected with a nerve. It does not enable its possessor to see, in our conception of the word; it gives little more than a sense of heat. But it establishes a connection between the life within and the light without. It cannot form optical images, but it can and does respond to the stimulus of light.

Photo by R. W. Shufeldt

SNAKE'S HEAD AND EYE

THE SIMPLEST EYE MACHINES

No creatures have eyes more elaborate than are needful for their life business. If they do not need an elaborate self-adjusting focal lens they do not have it. Eyes begin with skin windows, slightly rounded. Why rounded? To know the reason we must go back to some information about light and its ways which we already possess. Light travels to a surface in straight lines. It never turns sharp corners. It goes through a flat transparent window and keeps on without change of direction, without, to put it more technically, the image being distorted. By image we mean at this moment the picture which is to be made on the sensitive surface of the eye. Light hits a mirror and is reflected straight back; again, the image is not distorted or in any way pulled out of shape. In these cases the image or picture is formed by the curved lens in our own eyes. If the light rays traveled straight to the back of the eye, we should get a very blurred image. But they are bent in the eyeball by a transparent curving substance, a lens, so that they come together at a point, a focus. Look at the drawing on page 199, and you will see what is meant. To the area where the picture is formed comes the optic nerve, which carries the impression to the brain. This is the principle of an eye machine like our own, with a curving surface which light rays strike, a transparent lens to bend them to a focus, a retina or sensitive plate to receive the image, and the optic nerve leading to the brain. On this general plan are worked out all the eye machines of higher animals; to it the simplest eye machines of the lower animals tend.

WINDOW AND LENS

In the snake we find the slightly curving window which helps to bend the light rays toward a point. This bending together collects the rays so that they may form some sort of a blurred image. It was a great day, as Dr. Edward Ayers points out, when lenses were introduced in Nature's eye factory. From light as seen through tissue paper to pictures as seen in focus is a great improvement. From the crude eye window with its curving surface there is a constantly ascending scale to the focal lenses of bird, beast, and man, with their possibilities of far and near sight, of quick adjustment and clear, sharp impressions. To study them all would require a separate volume. Let us take some of our familiar acquaintances in the lower creation, and see with what kinds of eye machines they are equipped. Each, as we shall discover, will have just as much possibility of sight as he can use in daily life, — no more and no less.

A THOUSAND EYES IN ONE

Our insect neighbors have two kinds of eyes, — simple eyes with their light-sensitive surface and nerve connection, and compound eyes, which are thousands of unit cone-shaped eyes put together. The remarkable photograph of a cross section of a compound eye on page 186 shows better than words can tell how one of these compound eyes works. The lens or transparent window is at the outside, the cone behind it tapers to the sensitive nerve area. Dr. Ayers gives a word picture of the possibilities of such compound eyes which we cannot do better than share with our readers. "Each glistening facet is the cornea lens of a distinct self-working eye. Their number in each compound

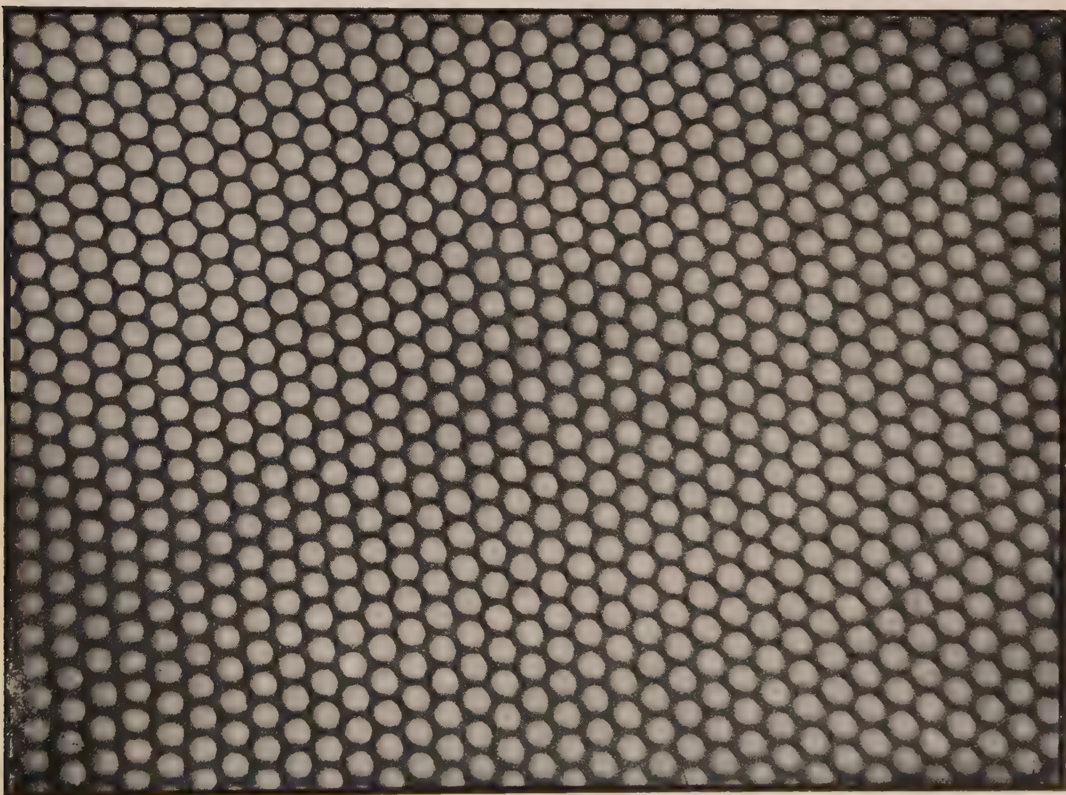


Photo by W. F. Watson

SECTION OF COMPOUND EYE OF BEETLE

Each unit of the pattern is a tiny separate lens, one of the six thousand which make up the compound eye of a beetle. This photograph was taken through a microscope which magnified this tiny portion of the eye surface so that its structure could be seen.

A CROSS-SECTION OF THE EYE AND A PART OF THE BRAIN OF THE HONEYBEE

This picture shows how from each lens of a compound eye a nerve runs back into the brain of the insect. These lenses or windows are on the outer curve at the right. 1, 3, 4, 6, and 8 are heads of insects, showing position of eyes; 2, 5, and 7 show the corresponding lenses.

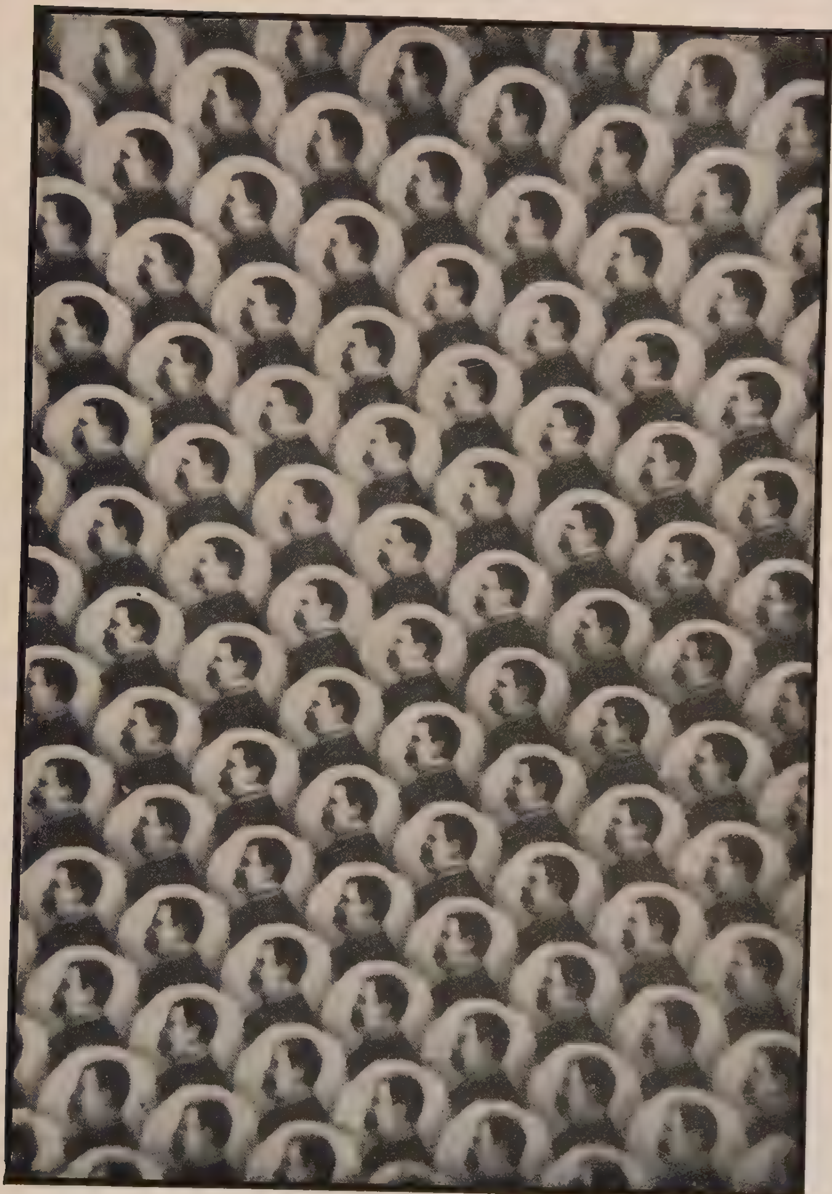


Photo by W. F. Watson

AS SEEN THROUGH A BEETLE'S EYE

In the camera was inserted a cross section of the eye of a beetle, and the man's photograph was taken through the beetle's eye. Does the beetle see a separate picture for each of its six thousand lenses, as the photographic plate received an impression for each lens of this cross section? Probably not, any more than we see two images through our two eyes. Back of the eye lies the brain, which translates the impression for us; the tiny brain of the beetle may perform the same marvelous feat.

eye is enormous. There are fifty such eyelets in each in the ant; 1400 are allowed the drone bee, and 3500 the 'workers.' Our pet kitchen fly has 5000 chances of seeing food crumbs, the beetle over 6000, while more than 13,000 aid the dragon-fly in his eleemosynary pursuit of the mosquito, offset somewhat by several thousand awarded the latter for a 'sporting chance.' The hawk moth gets pictures compounded by 20,000 contributors.

Over 25,000 window the brain of the Mordella (beetle), and 60,000 — so it is claimed — contribute to the happy lives of some butterflies." By this system of compound eyes insects can see in all directions at once.

How these eyes see has been and is still a matter of discussion in the scientific world. It is our good fortune to be able to reproduce photographs taken by Mr. W. F. Watson through the lenses of compound eyes. What this means in the way of painstaking effort and miraculous skill it takes a moment of thought to realize. We with our unaided vision would find it hard to distinguish these insect eyes. Under a microscope a compound eye would look like a mosaic pavement, transparent and glittering. Mr. Watson managed to dissect from the insect such a tiny compound eye, with its thousands of separate lenses, to mount it by itself, uninjured, and then so to place his camera as to photograph through it. The result is marvelous as a triumph of mechanical ingenuity, and most interesting in its contribution to our knowledge of vision. Each eye, as the photograph shows, gets its own reflection of that part of the surroundings directly before it. Just how much of a picture and what kind of a thousand-in-one picture is conveyed to and interpreted by the brain of the beetle, we cannot, with our superior powers and understanding, pretend to fathom. But, at least, Mr. Watson has permitted us to look with him through the eye of a beetle, an experience which brings us nearer to understanding than we have ever before been.

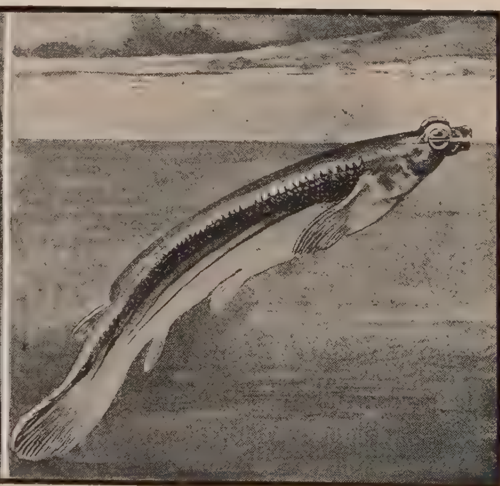
NEAR AND FAR SIGHT

Insect eyes have fixed focus; their lenses are not adjustable for near and far sight. Single eyes are set for short focus, probably, according to Vernon Kellogg, with a range of only an inch or two; compound eyes have a longer range, probably two or three yards. Many insects have both kinds, — a trio of single eyes, set close together, and a pair of compound eyes. For insect purposes these are like grandmother's spectacles,—one set for near sight, one for far sight.

Most fish are nearsighted. This is as one would expect in a water world, where, even with his perfect vision, Professor Longley could see, as you will remember, only a few feet. The light is dim and shadowy in the world of the fishes. So the pupil of the eye is large, as the pupil of a cat's eye will enlarge to catch all the light there is. The lens is a sphere with its front surface somewhat flattened to catch every ray of light as it passes through the water. When the fish wishes to look in a certain direction, he can pull the whole lens around toward the object he wishes to examine, and do it quickly.

EYES IN HIS FINGERS

This shrimp has eyes farther from his head than any other animal. It seems as if he could swing those long feelers round so that he could look back at himself.



EYES FOR FAR AND NEAR SIGHT

This fish will never need bifocal glasses, for he has two sets of eyes, the upper ones to use above water for far sight, the lower under water for near sight.

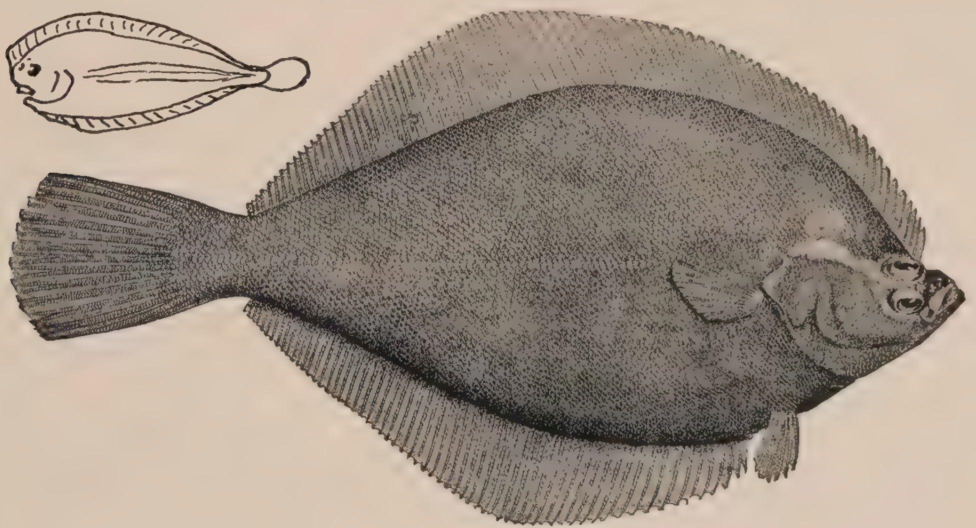
This kind of eye adjustment by moving the lens has been likened to man's use of a pair of opera glasses, in which he moves the lens nearer to or farther from the retina.

A FOUR-EYED FISH

Of all the strange eyes none is more extraordinary than that of the South American fish "Four-eye," or Anableps, which lives in the estuaries of Brazil and Guiana. "Spectacles for human eyes are sometimes made in which the upper half has a curvature different from that of the lower." Four-eye "does not wear spectacles, but actually has his eyes made in two parts, the upper half of the lens having a different curvature from that of the lower. . . . This fish is in the habit of swimming at the surface with his eyes half out of water; the upper half of the eye is adapted for vision in air; the lower half for vision under water." So far as the habits of these fish are known, they seem to get their food from small creatures which are to be found along the surface of the water. Sight above water is, therefore, important to them. They swim along at the surface, in small "schools," the upper half of the eye of each fish out of water, as shown in the picture, the remainder of the fish submerged, with its part of the eye adapted to sight in the dense medium of water. This is a remarkable example of life in two zones, and of adaptation to such life.

AN EYE THAT TRAVELS

The flounder has a curious life history, so far as eye position goes. He starts life an upright, rounded little fish, swimming as other fish do, back up with two well-balanced sides, and with two eyes, one on each side of his head. But while the baby flounder is very young, an irresistible inclination comes over him to take to the bottom of the sea. He seems to become aware that flounder life is best spent lying inconspicuously on the sand, catching what food comes within his range. So he lies down on one side. If this was the end of the matter, physiologically, he would lose entirely the advantage of the sight of one eye. But as he takes this position, his form begins to change. The roundness disappears; he becomes as "flat as a flounder" and, most remarkable of all, the eye on the under side slowly shifts its position and moves around the head until it comes out on the upper side. There you see it in the picture, settled in its new position, ready to do service, gazing upward.



AS A FLOUNDER'S EYE TRAVELS

In the small drawing a baby flounder is shown, rounded, with back up and an eye on each side of the head. The adult flounder is shown, flattened out and lying on one side on the bottom. Meanwhile the eye from the lower side has traveled around to the upper side next its mate. (*Shufeldt after Goode.*)

EYES ON FINGERS AND TOES

The old nursery rhyme of the favored personage with "rings on her fingers and bells on her toes" might be adapted to describe those creatures who carry their eyes, not in the usual positions of head or body, but on their outreaching limbs or feelers. It is like solving a riddle to attempt to figure out the possibility of eyes thus placed at arm's length from the body. Can the shrimp of the picture, whose eyes are at the tips of his long feelers, look back and see himself? "Foot-eyed" creatures, these shrimps and crabs and lobsters are called, which bear their eyes at the tips of long movable stalks. Our common garden snail carries eyes at the tips of his flexible horns. There is common sense in this method of eye placing. The snail cannot raise his head to gaze about on the surrounding scenery; he has no legs with which to lift his entire body; he has no neck to hold his head and eyes aloft. Eyes placed on the central body would have a very limited view, which would hardly suffice to get Mr. Snail a living; but with eyes waving about on these long horns, he can survey the landscape o'er, so far as the range of his eye machine allows, and see both the spot to which he is progressing and the dainty tidbits which are to be found along the way.

Insects get a sufficiently wide range of vision for their food-getting needs by their compound eyes, which are situated at convenient places on the body, and the simple eyes, which are often more centrally located. The starfish has eyes at the tip of each of his five rays. The leech has eyes guarding his mouth. All are placed with due regard to the creature's needs. "If the spider cannot bend his neckless head nor move his socket-fixed eyes, he gets one for each point of the compass, whereby he can keep one eye on his struggling menu fly, and as many as are needed upon the straining halyards and guys of his gum thread web. And each eye is set high, like a lantern on a hill, so its wide range of vision makes eye rolling useless."

HOW THE CHAMELEON SQUINTS

Man moves his eyes to right and left without turning his entire head; animals, especially the lower creatures, are more likely to turn the whole head when they wish to look beyond the range of vision at the moment afforded by their position. The chameleon's eyes are remarkable in that the right and left eye can be moved independently of each other. The eyeballs of the chameleon are very large, as can be observed in the picture on page 136, and as he rolls them rapidly back and forth, looking with one eye at a tree on his left and with the other at the ground on his right, the effect is of a worse squint than any cross-eyed human being ever perpetrated.

THE SIZE OF EYES

"In general," says Wilder, "the size of the eyeball is somewhat in proportion to the size of the body, yet the eyeballs of the elephant and the whale, although large in both cases, are not proportionate to their enormous bulk when compared with those of man, for instance. Again there is a certain proportion between the size of the eyeball and the sharpness of vision, as, for example, the enormous eyes of birds; but here, again, must be mentioned the small but exceedingly acute eyes of rodents." If eyes were in proportion to body weight and birds' eyes were set as the standard, whales' eyes, which measure two inches to two and a half inches across, would be larger than wagon wheels. Our own eyes, if proportioned pound for pound with birds' eyes, would be like automobile lights, eight or ten inches across. Birds' eyes, so large in proportion to a bird's size, are also most delicately and beautifully fashioned. If, as is often said, the eye of a creature is the best index of its advancement in life's race, birds are proved by this as by other signs to be high in the scale of life development.

A BIRD'S-EYE VIEW

Only in the last ten or fifteen years, and especially in the last five years, has man become sufficiently skilled in navigating the kingdom of the air to know what a real "bird's-eye view" is like. Photographs taken from airplanes give us an idea of its tremendous range; stories told by aviators indicate the strain put on the eye by the need of rapid changes of focus for near and far vision.

"Birds," writes Dr. William Beebe in his book on "The Bird: Its Form and Function," "so wonderful and interesting in all their structure and life, have that most treasured of all the senses — sight — so highly developed that there is nothing with which we can compare it among living creatures. With our great telescopes we can see to a greater distance than any bird; with the high-power lenses of our microscopes we can distinguish infinitely smaller objects than any feathered creature is capable of perceiving, but where else on earth is there an organ of vision which in a fraction of time can change itself from telescope to microscope; where is the eye that, seeing with wonderful clearness in the atmosphere, suddenly adapts itself to the refraction of water, or to the darkness of night?"

"The faculty of *accommodation*, that is of adjusting the focus of vision, is developed to a marvelous degree; rapid, almost instantaneous changes of the visual angle being required for distinct perception of objects that must rush into the focal field with the velocity at least of the bird's flight. Observe an eagle soaring aloft until he seems to us but a speck in the blue sky expanse. He is farsighted; and, scouring the earth below, descries an object much smaller than himself, which would be invisible to us at that distance. He prepares to pounce upon his quarry; in the moment required for the deadly plunge he becomes at once nearsighted, seizes his victim with unerring aim, and sees well how to complete the bloody work begun. A humming bird darts so quickly that our eyes cannot follow him, yet he instantaneously settles as lightly as a feather upon a tiny twig. How far off it was when first perceived we do not know; but in the intervening fraction of a second the twig has rushed into the focus of distinct vision from many yards away."

It is a far cry from the simple eye of the insect with its fixed focus and near sight to the perfected eye machine with its highly adjustable living lens and the surrounding muscles and tissues by which it is controlled and in which it is encased. When we study the human eye we shall see how its adjustments parallel many of those in birds' eyes. As can be seen by the photographs in this volume, the eye of a bird as we look at it appears round. It is set in a cavity, more or less deep according to the species of bird, and is carefully protected by muscles, cushions of fat and projecting bones of the skull. The eyes of some birds look like round, shiny beads; the eyes of others look like human eyes, with the surrounding accessories of eyelids and other skin protection. The eyes of the barn owl are set deep in the skull. The bright eyes of the eagle have an overhanging brow or ridge. When we consider how high the eagle flies, it is evident that this eye is set in exactly the way best suited to his needs. He cannot look upward as readily as some of his fellow birds; but to what purpose should he gaze skyward? His prey is far below him. Rather he needs and has the protection of overhanging brow as a shade from the over-bright light from above, as a person standing in bright sunlight on a high mountain shades his eye with his hand for clearer vision.

Photo by Finley and Bohlman

CANVASBACK DUCK

With small round eyes looking straight ahead in this photograph, yet so placed that they have a side view as well.

Photo by Finley and Bohlman

OSTRICH PORTRAIT

Human-looking eye and strong leathery beak.

A THIRD EYELID

Not only do most animals above the rank of fishes in the scale of life development have eyelids, but many of them have a special third eyelid, of which only a slight trace in the form of a bit of skin at the corner of the eye remains to man. Fishes do not need eyelids to protect the eye, for the fish eye, like the rest of the fish body, is safely cushioned and protected by the surrounding water. Eyelids are a necessary development involved in the change from life in the water zone to the air zone. They serve an important purpose in keeping the eyeball moist and clear of dust. Man makes most use of his upper eyelid in covering the eye; birds use for this purpose the lower lid, which comes far up over the eyeball.

In sleep birds close their eyes, but during their waking hours, when vision is all-important to them, especially if they are hunted creatures, they do not relax their vigilance even to the extent of shutting out vision by winking with the two curtain eyelids. Instead, they whisk across the eye with incredible swiftness a delicate semi-transparent veil of tissue called the "nictitating" or "winking" membrane. With this eyelid they get the benefits of winking without its disadvantage of total, though temporary, loss of sight. "When you see an owl in the daytime with eyes dull and glazed, this third eyelid is drawn partly across them, diluting the strong glare of light and yet enabling the bird to distinguish much that is going on. When an eagle turns his head upward and looks full at the sun, it is not 'unwinkingly' but with the help of this eyelid shield."

A NEW EYE EACH YEAR

Higher animals and human beings carry through life the eye with which they start; snakes have a new eye window or eyelid each year. An eye window of transparent skin with no moving lid is entirely adequate for snake life. But even the hard, bright varnish with which the skin of the eye is coated does not save it from becoming scratched and defaced in time. There is no movable curtain to shut down automatically at the approach of any foreign body and protect it. Snakes can never close their eyes, for there is nothing with which to close them. But once a year, when the skin of the snake is to be shed, the skin eye window is thrown off, and the snake starts again with a new window of freshly grown skin, well varnished. From the fact of this annual change comes the saying that "snakes wink once a year." How wink without an eyelid, except to wink away the whole eye?

It is a distinct effort for us to look steadily at any object for a long time. The lack of an eyelid gives the snake that fixed gaze with which it is said to charm and terrify a bird. The snake has only to hold his head still; the gaze of his beady eye cannot but be unwavering.

DO ANIMALS WEEP?

Animals have tear glands; these tear glands supply a sufficient amount of tear fluid to serve the original purpose of such glands, namely, to keep the surface of the eyeball moistened and free from dust, as the movement of the eyelid spreads this liquid evenly over the eye. In this sense animals are not tearless. It is said that there are occasions when deer have been known to have the flow of these glands increased under stress of pain or panic, and they might therefore be said to "weep" at such times. There may be similar reports of other highly developed animals. But naturalists agree, in general, that tears as a sign of emotion are shed only by man. Man alone weeps from sorrow, joy, chagrin, or other feeling.

EYES THAT SHINE AT NIGHT

Every one is familiar with the way a cat's eyes shine at night. Many other animals have eyes which gleam in semidarkness. "These almost self-luminous lights," writes Dr. Ayers, "are a flare from the inner wall of the posterior chamber of the eyes. . . . The inner chamber of the eye lying behind the lens is in many animals lined with a membrane not possessed by man, called the 'tapetum' (tapestry), which gives a highly lustrous metallic reflection, greatly differing in various animals. Between tapetum and retina the animal eyes reflect all the colors found in an artist's paint box. The eye-chambered walls of the chimpanzee are hung with tapestries of deeper chocolate than is found in the Nubian youth. The black-eared marmoset prefers slate green mural decorations; the seal, Naples yellow; the hyena, Nile green and lilac; the jackal, bright yellow and deep violet; the skunk, a dusky sunset hue; the black bear, green and red brown; the camel, brownish red; and the elephant, as unattractive a mixture of brown and muddy yellow as his hide presents."

"This layer," according to J. Arthur Thomson, "includes numerous flat cells packed with crystalloid bodies which act like a mirror. In some beetles and moths the eyes shine like rubies when they are obliquely illumined at night. . . . It is probable that the reflection of the light rays from the tapetum is advantageous, since the visual cells are thus affected twice instead of once."

Photo by Wm. L. Finley and H. T. Bohlman

BARN OWL, THE BIRD OF NIGHT

The owl has deep-set eyes that penetrate the darkness of the night.

IF EYES ARE NOT USED — THE STORY OF CAVE ANIMALS

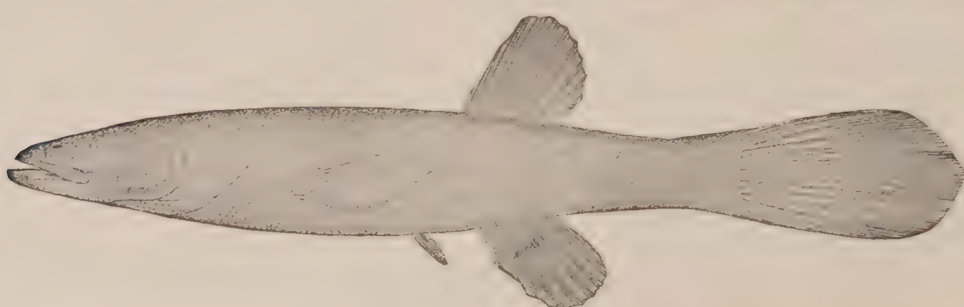
Nature is strict in the giving out of supplies. If eyes are not used, they gradually disappear. A striking example of this is found in the study of cave animals, creatures which spend their entire lives in the total darkness of caverns. In our country the Mammoth and Wyandotte Caves have been especially explored, and careful studies made of their living inhabitants.

Blindfish (*Amblyopsis spelaeus*) is one of the most interesting of these dwellers in the dark places of the earth. It is a pale, colorless little fish, about four inches long, and totally blind. Blindness to us means having eyes which for some reason fail to function; in the blindfish it means having no eyes at all. Yet there are traces of eyes to be plainly seen in the young blindfish. The idea used to be that when generations of these fish had lived in caves, not using their eyes, the eyes gradually disappeared. This is a disinheritance theory, young fish after many generations of decreasing sight finally having failed to inherit possibility of sight. Nowadays a group of scientists say that fish that had poor sight may very likely have made their way into the dark caves and found life there entirely satisfactory. So they stayed, and very naturally their children and children's children had only partial or perhaps no sight. However it may have come about, not only fish but many other cave dwellers are without eyesight; salamanders, crayfish, beetles, and other insects living in Mammoth Cave have all been proved to be blind.

Nature maintains a just balance. When sight is withdrawn as useless under conditions of complete darkness, other powers, like touch, are greatly developed. But that, as Mr. Kipling would say, is another story, to which we come later.

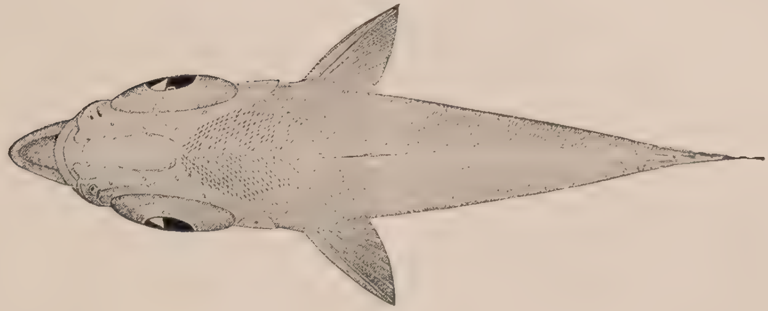
IN THE DEPTHS OF THE OCEAN

In deep-sea fishes there are two types of reaction to the absence of light. Certain fishes, like the cave animals, become blind. The eyes grow small or in some cases disappear. In other cases, as is shown in our sketch, the eyes instead of becoming smaller grow larger, as if in an attempt to catch every ray of light. They become, as Hussakof has expressed it, like enor-



CAVE FISHES WITH SMALL EYES AND NO EYES

Creatures that live in darkness have no need of eyes. In the fish shown at the foot of the page the eyes have disappeared, leaving only a mark where they would normally be; in the fish at the top the eyes are very small. (*Shufeldt after Goode.*)



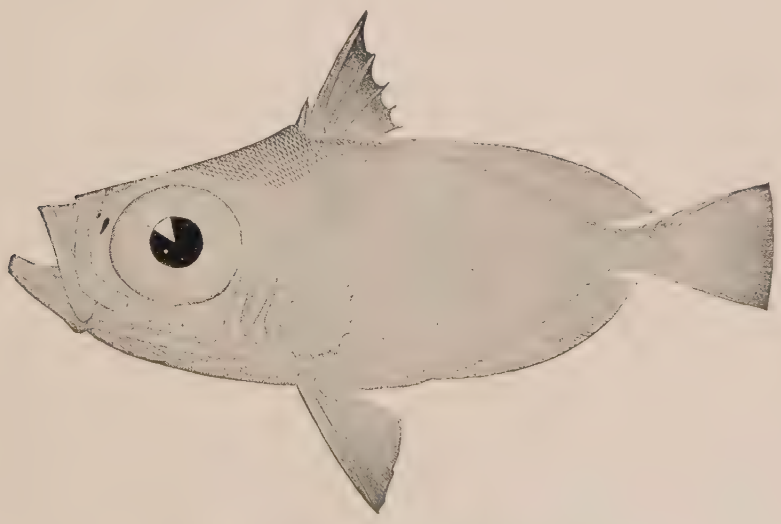
mous goggles or headlights. Most deep-sea fishes have luminous organs of some sort. They give out light from themselves. There is therefore something for the deep-sea fish to see, if he keeps his eyes.

IN OTHER WORDS

"To my mind, the most wonderful achievement with animal machinery, aside from abstruse thinking, is the ability to handle the rays of light. . . . The speed of the snail is far nearer the rush of the whirlwind than the speed of the wind to that of light. . . . How can our eyes sense anything so without weight or substance and grasp as they do the thousand lines, shades, scintillations, and iridescences that flood the earth? And yet every puppy-dog, every ephemeral insect, can work this magical performance without taking thought.

"There is no known limit to the possibilities of transmission or storing of complex vibrations or their reproduction as affecting our sense organs. . . . Light mechanism differs from that of sound not only in being much less mechanical, more immaterial, but enormously more speedy and unthinkable. . . . Fire a 16-inch projectile and snap a shutter at the same instant, and the rays of the uncaged searchlight will illumine the far-distant target before the iron mass has flown a hundred feet. Face the moon with closed eye, and before you can open, shut, open again, and close the lids, silvery light-waves will have started from the moon, rushed past your lids during their second opening, and dashed millions of them against the rods and cones of your retinas and set them vibrating at a known mathematical series, which we sense as a whitish orange-yellow silvery moonlight. — EDWARD A. AYERS.

"Well may we affirm that every part of the world is inhabitable. Whether lakes of brine or those subterranean ones hidden beneath volcanic mountains — warm mineral springs — the wide expanse and depth of ocean, the upper regions of the atmosphere, and even the surface of perpetual snow — all support organic beings." — CHARLES DARWIN.



DEEP-SEA FISHES WITH VERY LARGE EYES

In the dark depths of the sea there are blind fishes, but there are also fishes like the one here shown in two views with eyes very much enlarged as if to catch and hold every possible ray of light. (*Shufeldt after Goode.*)

THE HUMAN EYE

Its marvel as a piece of machinery, its mysterious power of responding to ether as does no other human sense organ.

THE human eye is the masterpiece of Nature's eye factory. It is the last word in sense organs, Nature's triumph in their evolution. Beyond these mechanical perfections — and they are a marvel in themselves — it has a romantic and compelling interest. It is the foremost sentinel, the most adventurous outpost on the frontiers of that world of wonder which lies almost if not quite beyond our ken.

THE BRAIN COMING OUT TO SEE

There is a truth that goes beyond the details of cell structure in the fact that the eye is actually the brain coming out to see. The optic nerve is physiologically a part of the brain; the retina, without which there can be no vision, is in very truth brain substance, magically capable of receiving light waves and transforming them into nervous impulses, which the brain, in its turn, conveys to our consciousness. Where brain is concerned, there lies magic and mystery. We have stepped from the matter-of-fact and limited world of the physical into the free and unbounded kingdom of the mental. We can say with the poet that

> "Since eyes were made for seeing,
> Then beauty is its own excuse for being."

The beauty of the world is poured in on us through the delicately adjusted machinery of the eye. In a world of surpassing glory of form, shape, color, of shade and tint, the brain did well to press out into a film whereon could be caught the world's reflection. Conversely, the image of the life within is dimly caught and mirrored in this ever-changing and responsive outer organ. Each other sense organ is hidden away in the body. The inner ear is approached only through the outer and the middle ears; all that is visible on the surface is a fold of skin shaped to catch and direct sound waves. No stress of mind or body changes its outer appearance. Taste, touch, and smell have no visibly responsive outer organs. But the eye is the window of the soul. When blindness overtakes an adult, it is for his friends as if a curtain had been pulled down over his visible emotions. No longer are the rapid changes of his thought and mood reflected in this ever-moving, beautifully changing organ of the body. The light has gone out from his eyes.

This light itself, of which we speak so familiarly — have you ever paused to consider what a mystery it is? We talk of it glibly; we have learned to number its vibrations, and to name and grade it in the terms of these vibrations. But what is it that vibrates? Ether, we say. And what is ether? That which fills all space. Have we seen it, can we touch it or taste it, handle it, weigh it, or in any way "sense" it? Not yet. Those mysteries are still to be unlocked, although it is thought that at this moment science has in its hands some of the keys which will fit the locks and swing the doors ajar. But the eye responds to this ether. Alone of all the sense organs it is responsive to it. The ear, for all its elaborate mechanism, responds only to tremors of the air. Touch, taste, smell, muscle pressure, balance, — all are concerned with matter. This sight feeler that the brain has sent out responds to the ether of space. "It catches its vibrations," says Sir Oliver Lodge, "and we call the shiver or the tremor light." No one has ever seen light. We still perceive only matter; we see only the object which emits light. But the physical body was constructed, as you will remember, through the agency of light (caught and set at work in the green leaf); and this physical body, wondrously constructed by light and made vital by the impulse of life, is by a wonderful Providence become sensitive, through the highly refined organ of vision, to the vibrations of light.

In responding to ether movements the eye becomes the channel of possible information concerning a whole world which the telescope, the spectroscope, the microscope, and their many elaborations and variations are bringing daily more within the field of our knowledge.

The detailed structure of the eye may be studied in any physiology. Here we need only list the main parts with their functions, to enable us to understand the working principles and see how it is for our use an improvement on those eye machines of the lower animal kingdom with which we have been concerned.

THE WONDER OF THE RETINA

There are some subjects so complex as almost to baffle description. Yet in their very complexity lies a marvel which the most casual reader can appreciate and enjoy. The retina is such a subject. As an example of "much in little," it is unexcelled. Here is a nerve membrane, lining the entire back cavity of the eyeball, which is only six one-thousandths of an inch thick. This book, not counting the cover, is just under an inch thick, and contains about four hundred pages, or two hundred sheets of paper. It tàkes, therefore, over two hundred sheets of paper of this thickness to make an inch. It would take one hundred and sixty-six sheets of retina to make an inch. Hold between your fingers a page of this book, and you have about the thickness of the retina of your eye. Yet this retina is shown under the microscope to be made up of ten distinct layers.

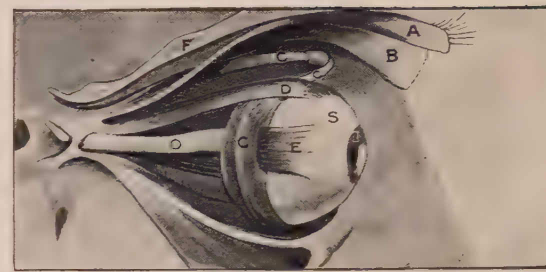
Some are of blood vessels, supporting tissues and nerves, all so transparent or so located as not to interfere with vision. One layer, the one of special interest, is that containing the so-called "rods" and "cones." These are nerve endings, some of them shaped like tiny rods, others like miniature cones, which seem to be the actual "transformers of light." Now for the marvel which you will find it hard to believe, but which will increase your respect for this eye film of yours. To make your vision perfect, or as nearly perfect as any instrument can be, this impressionable film has in its limited area three or four million of these rods and cones. Three million nerve endings are actually packed into one of the ten layers of the retina, a large proportion of them crowded together into a central part not bigger than the quarter of a dollar. These three or four million nerves, the rods having to do probably chiefly with intensity of light and the cones with color sight, connect with the fibers of the optic nerve, of which there are said to be about five hundred thousand. That is to say, the optic nerve is not a single nerve, but a strand made up of five hundred thousand fibers. That optic nerve carries the message to the brain; it carries it from a layer of the retina in which lie the rods and cones (rods 1/14,000 of an inch diameter, cones about 1/10,000), each of the five hundred thousand optic nerve fibers being connected, according to one writer, with seven cones and a hundred rods. It is easy to see how quickly this multiplies up into millions. The marvel is that our daily pictures of the world about us are, to borrow a housekeeper's figure, strained through so fine a sieve. Nor is man unique in possessing rods and cones. Not at all! They are found in varying proportions in eye machines far down the scale of animal life.

THE DARK CHAMBER

The retina, even with its power of receiving images and transforming light waves into nervous impulses, would be hardly more useful than the film of the photographic camera, if it were not for the focusing lens, the dark chamber, and the other parts of the camera. Directly in front of the layer of rods and cones of the retina comes what corresponds to the dark chamber of the camera, filled with a soft transparent jelly, called the "vitreous humor," through which light travels freely. This middle section of the eye is lined with black. The outside layer of the eyeball, within which lies this dark chamber, is what we see as "the white of the eye," the sclerotic coat.

THE LENS

Next, working from within outward, comes that very important part of the camera, the lens. We remember what a gain it was in eye machines when the curving lens was introduced. The lens of the human eye is of a clear, transparent substance as thick as jelly, with a front



THE OUTER EYE AND THE WORKING APPARATUS

The drawing at the left shows the eye as we see it, that at the right the eye from the same angle of view as we should see it if the framework of bone and the cushions of skin in which it is so carefully imbedded were removed. O is the optic nerve; A and B are muscles which raise the eyelid; C, D, and E, three of the six muscles which control the movement of the eyeball; F is bone, laid bare: S, the sclerotic coat, or white of the eye; I, the iris.

curve and a back curve; it is, in other words, a double convex lens, the convexity or curve not fixed as in a lens of solid glass, but adjustable through the pull of muscles which stretch or relax it as a rubber ball may be flattened or made to bulge.

OTHER PARTS OF THE EYE

To this lens light must be admitted, even as light must be let in to the lens of the camera. The surface of the lens is protected by a liquid, the aqueous humor, which fills the front chamber of the eye. Directly in front of the lens the sclerotic coat, the white of the eye, becomes transparent, forming the cornea, which is the window of the eye, through which light enters. Behind this window, across the front chamber of the eye, lies the iris, which is a circular curtain for the window. In the center of this iris is the hole known as the pupil of the eye. The iris is what gives the eye its color, being brown, blue, or black in the human eye, according to the amount and position of the coloring matter in the cells of which it is made. The iris is a most delicate, automatic light adjuster, far more accurate in its adjustment than any man-made bit of machinery, for it responds automatically to every change in the amount and the brightness of the light falling on the eye. When the light grows brighter, it contracts, making the hole or pupil smaller until sometimes it is a mere pin point; when the light grows more dim it expands, letting more and more light in as the pupil grows bigger. The pupil of the human eye is always round. Such are the parts with which we are immediately concerned.

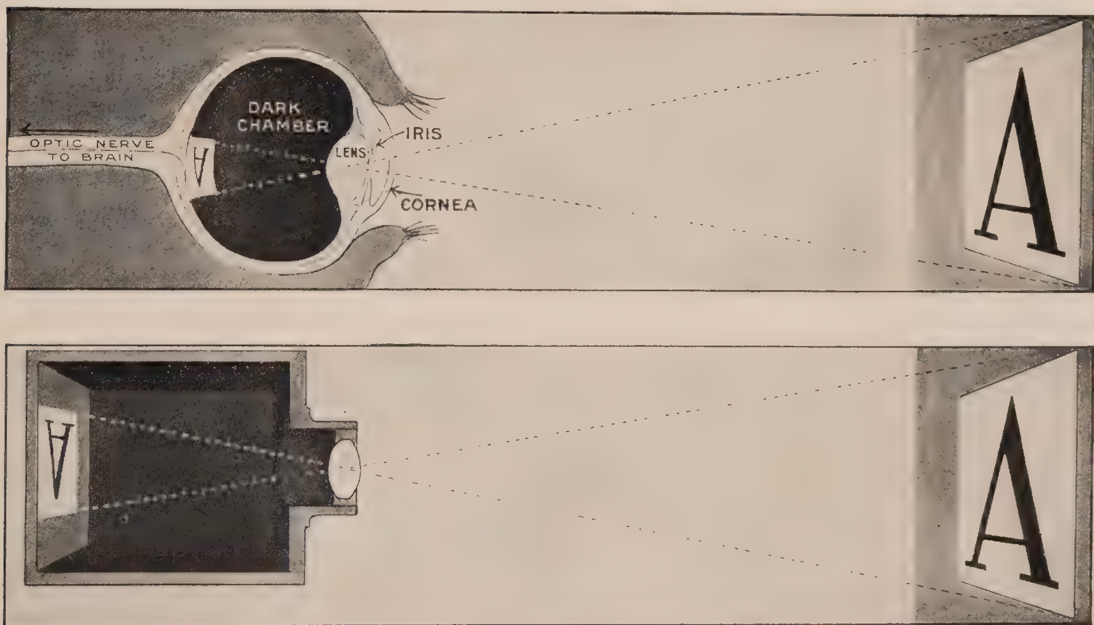
AS LIGHT COMES IN

Let us follow the track of light-rays from the letter A as they reach the eye. They fall on the cornea, the transparent window of the eye, which, by the way, has a thin outer layer for protection, called the "conjunctiva." They are admitted through the pupil, cross the aqueous humor, the liquid of the outer chamber, enter and pass through the lens, cross the vitreous humor and strike the rods and cones of the outer layer of the retina, are here transformed into nervous impulses, which pass by way of the retina and the optic nerve to the brain. Because light rays, while they may be bent as they pass through the liquids of the two chambers and the lens, cannot make sharp turns at right angles, they will cross as they do in the diagram, or as you have seen them do in a camera, and the image on the retina will be upside down. If you look through the back of the camera, the image on the film or plate will be upside down, as in the diagram. But in some mysterious way the nerves of the brain will right it so that our pictures come to us right side up.

AS YOU READ THIS PAGE

Animals have much less power to move the eyeball than have we. When the eye is to be moved, the head is turned. Our own power to move the eyeballs automatically and without any conscious attention depends upon the remarkable accuracy and delicacy of adjustment of the little muscles which move the eyeball. These are shown in the diagram on this page. A and B are not concerned in that particular

part of the story. They raise the upper eyelid. C, D, and E are three of the six little muscles which pull the eyeball about, their mates being in corresponding positions on the back or under sides of the eye. C starts from the rear of the eye socket and runs, just above the eye, through a little pulley. Then it turns back and down, spreading out over the eyeball. When this muscle is pulled, it turns the eye sideways, "rolls" the eye. D turns the eye up; its hidden mate pulls it down; E pulls the eye to one side, its mate pulls it to the other. "The extreme delicacy with which these muscles work is not usually appreciated. Especially remarkable is the accuracy with which they move when one is reading a printed page. The eye is perfectly directed to a certain letter, to comma or period, and then as suddenly turned, it may be only a hair's breadth, and the process repeated thousands of times in an hour, yet always with the most remarkable precision." It is when one or more of these muscles is strained or out of equal balance that the eye turns in one direction habitually, and the condition of "cross-eye" results.



THE EYE A LIVING CAMERA

The eye is here shown in diagram (above) as compared to a camera receiving an image on its sensitive plate (below). Both plates receive the image upside down, but before it reaches our human consciousness the optic nerve and brain have somehow managed to transpose it for us.

A SELF-ADJUSTING LENS

When the photographer wishes to turn from taking a picture of a distant object to take a picture of one a few feet away, he has to change the focus of his camera. He must move his lens backward and forward until just the right spot is found where the image formed is clear and sharp. The clearness of the image depends on the angle at which the light rays strike the surface of the lens, for on the angle at which they strike depends the amount they will be bent, hence the way they will come out on the other side, and the point on the retina where they will strike. The fish's eyes are near-focused. He can see objects very near the eye quite clearly. When he wants to look at objects farther off, he does exactly what the photographer does. He pulls the whole lens back, away from the cornea, toward the retina. That makes the light rays strike the lens at angles which will give a clearer image of the more distant object. That method works very well for the fish; it is the best the photographer with his solid glass lens can do. But men and birds improve upon it.

Their lenses are elastic and self-adjusting. Such a lens is like a rubber ball of flattened shape, which is controlled by a remarkably adjusted little muscle which pulls it up or lets it go automatically. Man's eyes at rest are long-focused. He can see the stars with no conscious effort. The lens is flattened in the resting eye. When he wishes to see a nearer object than that for which his focus is adjusted, this muscle pulls on the surrounding membranes and ligaments in such a way as to release the tension which keeps the lens flattened, and lets it spring back to its more convex (ball-like) shape. The front curve of the lens bends the rays of light more than if it were flat, like a window, and the image on the retina is thus kept clear and sharp.

TAKING CARE OF THE EYE MUSCLES

When the condition of the lens and its surrounding muscles is perfect, the eye accommodates itself readily and automatically to near and far sight. As we grow older the lens sometimes grows less elastic and responds less readily or the muscle of accommodation is not so flexible. In many individuals the lens tends to be more or less convex than is normal. Then the oculist tells the patient to "put on glasses," which will by the curve of their lenses make up for the deficiency in curve for either near or far sight, as the case may happen to be. When we realize how much work the muscle of accommodation does under normal conditions, we see why it is a serious and foolhardy matter to read in poor light or in a position that puts too much strain on this muscle. This bit of tissue is too precious and too necessary a servant to be abused and strained beyond its powers of recovery. Modern life puts a heavy strain on the eyes; thought must be taken for their protection. When one has been reading fine print or looking intently at small objects, as in following the motion of the needle in sewing, it is well to give the eyes an occasional rest by looking up and off at some distant scene, allowing them to come back to the focus they assume when at rest. To do this is like taking the pull off any muscle which has been held for a long time in one limited range of positions. To close the eyes for a moment serves even more speedily the same purpose. Remember these tiny muscles, and treat them as well as you would the muscles with which you lift a heavy weight.

IN SUMMARY

Such are the main parts of the organ of vision. That it is carefully guarded and cushioned, we know from our own observation. It is set in a bony eye socket formed by the bridge of the nose and the bones of brow, cheek, and temple, which is filled with a fatty cushion. It is supplied with quick-moving, automatically controlled shutters, the eyelids. It has a tear gland which keeps it moist. Only when tears flow from this gland at a rate more rapid than the normal is our attention called to its constant work. It has eyelashes and eyebrows to catch dust and perspiration and otherwise protect it.

MAN'S EXTENSION OF THE EYE

Man has caught the possibilities of this wonderful sight organ with its unique apprehension of swift-moving ether waves, and has sought by every mechanical means in his power to extend it. With his telescope he has enlarged the possible width of the light-receiving "hole," the pupil. The finest modern instrument has a lens one hundred inches wide. By its aid the light-receiving area is thus multiplied many, many times. With the telescope he can likewise throw his eye out from himself and seem to stand within hailing distance of a neighbor like the moon, although his feet are still planted upon solid earth. With the microscope he has extended his power of sight until hidden armies of hundreds of cells rise up to confront him. He has made photographic plates which are so sensitive that they can record sights which he cannot see, and can present them to him in photographic impression so that it is as if he saw them. He has even penetrated into the mysteries of the ultimate invisible constituents of matter and placed them in such relation that, while he could not actually see them, he could become aware of their movement through flashes of light recorded on a photographic plate. By his extension of the powers of his eye machine through these mechanical aids, man has proved himself in some measure a worthy possessor of this delicate instrument.

Photo by Wm. L. Finley and H. T. Bohlman

AN ANCIENT SENSE—THE SENSE OF BALANCE

Nature's gyroscopes, by means of which animals keep their balance on earth, in air, and in water.

IT is only in recent years that it has been recognized that there are more than five senses,— six, seven, probably eight or nine. "If a manager," wrote Dr. Ayers, "had seven bright and faithful messengers fetching him specialty information continuously through passing years, he would be thought strangely stupid if he knew only five of them. But if one was timid and insignificant, and another only appeared when the manager was ill or disturbed, his ignorance would be less marked. Five of our special sense organs — those of sight, hearing, smell, taste, and touch — have always been known to us. The sixth, our muscle-pressure sense, had to be dragged from a dim corner by physiologists to be recognized; while the seventh sense, insufficiently named equilibration, seldom makes itself known to consciousness; is, in fact, an automatic sense." This sense of equilibrium, or, as one writer puts it, of "up and down," is one of the older of the special senses; although making its appearance early in the animal world, it was one of the last to be recognized, studied, and described. This was partly because it did not have a special, separate outer organ of its own, but shared with hearing, in the higher animals, the inner cavity of the ear. Our own sense of equilibrium has for its chief seat the semicircular canals located in the labyrinth of the ear.

WHY IT IS NEEDED

The need of this special sense came at the moment when plants and animals parted,

plants choosing the safer portion of staying still, while animals seized boldly the chance to move. The sense of equilibrium has to reckon with gravity as a great, continuous, ever-active earth force. Plants, tied to Mother Earth, share its adjustments to the pull of gravity and need no special balancing organs. When creatures began to detach themselves from Mother Earth and move about in air, on the ground, and in water, it became convenient, oftentimes essential, to have an organ which should inform them of their own position, both when in motion

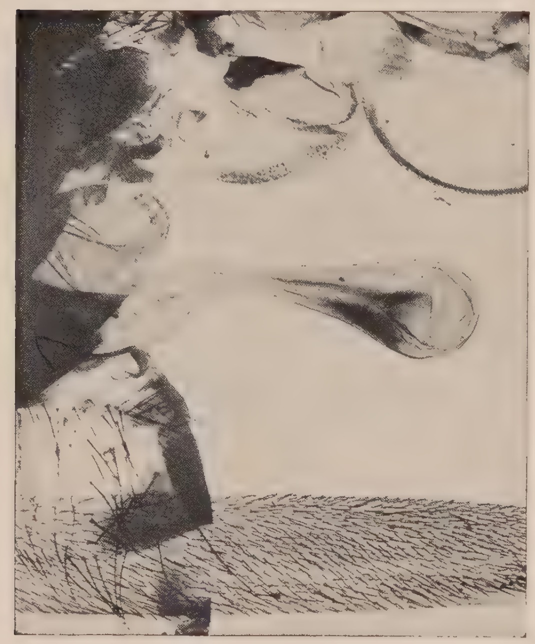


Photo by E. F. Bigelow

THE BALANCER UNDER THE WING OF A FLY
(Greatly magnified)

and when at rest, in regard to their surroundings. "With few exceptions," writes Baunacke, "the operation of these equilibrium organs is dependent upon gravitation and they give their possessors a sense of the vertical as a fixed direction and of the position of the body with respect to that line of reference." Other sense organs not only receive messages but deliver them to consciousness through the medium of the brain. The sense of equilibrium is in ordinary movement below the range of our consciousness and acts automatically. Put unusual strain on these organs, and the matter is brought to the attention. The child whirling rapidly in one direction experiences a sense of giddiness when he stops; the ocean traveler knows full well when the rolling and pitching of the boat puts too severe a strain on the organs of equilibrium; the aviator or the person descending in an elevator at too rapid a rate experiences a falling sense which is promptly communicated to the vital centers of life, the brain, the stomach, and the heart. Such experiences make us grateful to this silent, hidden "gravity finder" within our bodies.

THE FIRST BALANCERS

The first equilibrial organ is a globular sac filled with a watery fluid in which float one or more unattached solid particles. For water creatures the sac may be open and the liquid be the inpushing water. Sometimes these particles are of a chalky substance formed within the body; sometimes in sea creatures they are stones or grains of sand, collected by the creature and poked in through the open mouth of the sac. On the inner wall of the sac are nerve cells with fine hairs waving in the fluid. As the creature moves, this sac may be tipped from the vertical. When it is, the floating particle automatically seeks, in response to gravity, the lowest part of the cavity. In so doing it impresses upon the nerve cells of the sac wall stimuli which are carried by nerves to the central nervous system. From headquarters go out impulses which affect the parts of the body which have to do with movement. For instance, the body tips far to the right; the solid particle is promptly carried by the pull of gravity to that part of the sac which is thus brought lowest. The hairs and nerves coming in contact with the particle as it lies at the bottom of the sac "inform" — if we may borrow a word which implies a consciousness which doubtless does not exist — the headquarters of the nervous system that the body is tipped to the right. Instantly and automatically impulses for movement go out which cause legs, wings, or fins to move so as to restore the equilibrium of the body. The creature swings back automatically to a balanced position. It is a simple device, not so unlike a carpenter's level, with the added advantage that it can not only find the level but

also start the process of restoring the creature to balance. This may or may not be a "level" or right-side-up position. Many of the lower creatures may be in a state of apparently perfect equilibrium when they are at angles which do not conform with our own sense of comfort. A state of equilibrium may be maintained when the creature is at rest or when it is running, flying, or swimming. But the balancing organ is responsible for that state of equilibrium. Without it a pigeon or a fish may flop about in air or water like a drunken man. The balancing organ influences the mechanism which controls movement so as to produce or maintain, whether the body is at rest or in motion, a safely balanced position. It is Nature's gyroscope, or perhaps we might better say that the gyroscope is man's device for accomplishing the same end. (See Volume II, page 215.)

THE EAR A DOUBLE HOUSE

One of the reasons why this sense of balance was not discovered and designated as a separate sense is that it has no special outer organ of its own. The trio of semicircular canals (or the "vestibular system," as it is sometimes called) is in the ear. More accurately they occupy with the organ of hearing a deeply imbedded, much protected inner bone cavity in the head which is commonly called the "internal ear" or "labyrinth." Of the minute size and elaborate structure of this section of the human body, Dr. Ayers writes as follows: "The temporal bone of the skull, which extends underneath the brain in its middle portion, is hollowed out to form a Lilliputian cavern, a cast of which forms the labyrinth, or inner ear. In it lie the sensing structures of hearing and equilibration. If it were many times larger than it is, it would still be the most complex and puzzling structure ever created. As it is there are many diamonds large enough to contain it."

The ear receives vibrations from the outer air. It needs, therefore, all the receiving apparatus of the outer and middle ear. The balancing organ can be tucked away in this convenient inner chamber because it needs no contact with the outer world. Eye organs receive messages from light waves, ear organs from sound waves, taste buds tell of articles of the outer world brought into contact with them. "The equilibrial organs inform us, in distinction from all the other senses, not of the outside world's relation to us, but of our relations to the outside world." Being wholly concerned with the position or movements of the body, which they sense by internal means, they need no outer organ.

HOW THE BALANCING ORGAN WORKS

The equilibrial organs of man are far more complicated than the simple sac of the lowly water creature, but they work on the same principle of a liquid confined in nerve-lined membrane. The original sacs are here, with tiny chalky particles in them; but the system through which the liquid can circulate has been extended by the addition of three bony tubes curving in the shape of a half circle. These are called the semicircular canals. The scheme of circulation through the vestibule and the canals is not unlike that in the boiler and radiators of any hot-water system of heating.

The important feature concerning the three canals is their position. Each of the three corresponds in position to one of the general directions or dimensions of space. A room has length, breadth, and height. One of the canals is horizontal, parallel with the floor of the room; one is perpendicular to it, corresponding in direction to the north wall of the room; one is perpendicular to it and at right angles to the second canal, corresponding to the east wall of the room which cuts at right angles the north wall. These three planes represent the three dimensions of space. Each movement of a body may be considered a combination of movement in one of these planes. We tip the head from right to left; we are moving in the plane of one of the canals; we shake the head, and we are moving in the plane of another; we nod the head, and we are moving in the plane of the third. All possible movements of the head or body will be either in one of these directions or in a combination of two or more.

It is the business of the organ of balance to acquaint the brain with the direction in which the head or body moves. With the three nerve-lined canals in each ear, those of the right ear checking up or neutralizing those of the left,

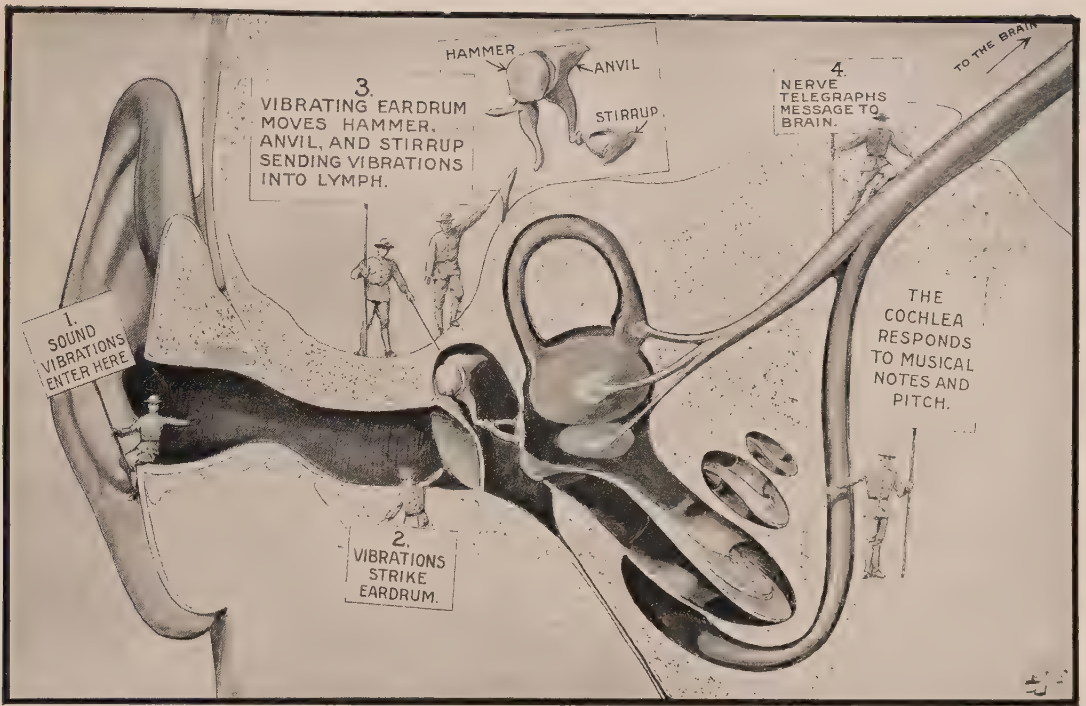
and with the vibrating liquid within them, it is possible for this organ to "sense" every slightest movement. With the liquid of the vestibule and cochlea and its tiny particles coming in contact, as in the simple sac balancer, with other nerves, it is possible for the center of balance in the brain to be kept equally informed of our position when in "static equilibrium," that is, when the body is at rest.

THE IMPORTANCE OF THIS SENSE

Since man has "taken to the air," and sought to imitate the performances of a bird, whose equilibrial organs are among the most perfect and highly trained sense organs in all the animal creation, it becomes a matter of vital import to him just how well his balancing organs work. One of the tests for aviators during the war was to place the subject blindfolded on a round wooden table-top which was so adjusted that it might be tipped from right to left, or revolved, or turned at any angle or in any way desired. The subject was asked to tell which way he was being tipped or how revolved. This was a test of that sense of stability and balance which he must for his safety's sake possess and cultivate if he were to venture into the air and control a machine moving in three dimensions. If he was too much affected by dizziness, he could hardly expect to become a pilot; on the other hand, if he did not experience a certain degree of dizziness, it was clear that his equilibrial organs were not sufficiently developed for aviation purposes. This was only one of many tests, but it illustrates a method used to find out how well these important organs worked. Investigations during the comparatively few years in which man has managed airships indicates that "conscious stability and comfort in the air depend primarily on the normal response of three groups of sense organs," — those in the ear, of which we have been speaking, the eyes, and the so-called muscular system, with its endings in muscles, tendons, and joints. The eyes and the muscles work with the balancing organs.

MAN'S THREE SEMICIRCULAR CANALS
(Greatly magnified)
For position in the ear see drawing on opposite page.

Because the seat of the balance sense is out of sight, we are apt to leave it out of account. The aviator could not balance himself without the aid of his semicircular canals; but he notices more the muscular and sight contributions. "We find," says Dr. Ayers, "in practically all feats of equilibration that the fundamental non-conscious sense is assisted by the conscious senses, sight, touch, and muscular pressure; and that we casually award all the credit to the latter three senses. They are the steering gear of the ship, but the canals are the ballast in the hold. . . . The equilibrial organs are believed to sense wholly by internal means, and without assistance of other senses, the direction of gravity; of motion, its direction, speed, cessation; to sustain tone or tension in such muscles as keep the body, when awake, in equilibrial balance; and assist the cerebellum in working many combinations of muscles co-ordinately — harmoniously — to perform given acts." Destroy one of the canals; the pigeon cannot fly straight, the fish swim normally, or the man walk in the dark without staggering or swerving to right or left.



A PICTORIAL DIAGRAM OF THE HUMAN EAR, GREATLY ENLARGED

NATURE IN THE TELEPHONE BUSINESS

Of outer ears and inner ears, of ears that move and ears on legs, of the wonders of hearing as found in the animal kingdom.

SINCE man has himself made sound receivers and sound transmitters, he is prepared to look with renewed respect on the living machines with which Nature equips its children. Ears are Nature's private telephones for the reception and transmission of sound.

Sound comes to all living creatures in waves. Its vibrations can be perceived only by the proper kind of instruments. Some of these waves come very slowly, eight or ten vibrations in a second. They make a certain pitch of sound. Others come very fast, forty or fifty thousand vibrations per second. They make a very different sound. The vibrations which the human ear distinguishes lie within this range of vibrations. A huge sound keyboard might theoretically be laid out which would have between its foot and its head all this scale of sounds. When we are told that a trained ear can distinguish more than one thousand shades of pitch in one octave, we begin to realize the marvel of our human ears and the intricacy of ear-making as Nature must practice it. Let us begin by following a sound wave through the channels of the human ear.

OUTER AND INNER EARS

The portion of the ear which lies outside the skull is made up largely of skin, with a few pieces of cartilage to give it shape. It is the least important part of the human ear; indeed, we could hear very well without it, though it serves to collect sound waves. In some animals this outer ear is very large and is prepared to serve an important part as an ear trumpet to collect sounds, but in man it has only a minor part to play. The sound waves of the air pass into the tube of the ear and come to a little partition separating the outer ear from the inner ear, which is the real organ of hearing. This partition, a delicate and important membrane,

is called the "eardrum," or "tympanum" which is the Latin word for "drum." Beyond the eardrum lie three odd-shaped bones, which can be seen very plainly in the drawing. First, with its handle against the eardrum, comes the "hammer." The round head of this hammer rubs against the "anvil," and the anvil pushes a little bone called the "stirrup."

The sound wave hits the eardrum, setting it vibrating. The vibration of the eardrum starts the trio of bones swinging. The stirrup is pushed in and out of an oval hole in the wall of a chamber that is filled with liquid. Every movement of the stirrup shakes the liquid. (A membrane joins the stirrup to the wall, so that the liquid does not run out, but is kept in its chamber.) Through the outer tube the vibration has come and struck the eardrum, which has vibrated at exactly the rate of the sound wave. The vibration has been passed on by these little bones, still at exactly the same rate; it is taken up by the liquid at exactly the same rate. This liquid is in the labyrinth, that tiny bony cavity packed with the precious organs both of hearing and of balance. Here are the nerves and fibers which will take up the vibration and transform it into a nervous impulse, which will hurry on its way to the brain. Here is the cochlea, that complicated and most interesting tube, which contains the apparatus for distinguishing musical notes and pitch.

EAR AND THROAT

Interesting as the subject is, we should promptly find ourselves far beyond our depth in scientific thought and speech if we tried to penetrate the workings of this inner ear. Even scholars do not agree as to many of the details, nor do they consider that they have fully solved its mysteries. A few more facts about hearing will, however, be of interest.

The eardrum, as can be observed in the picture, is not a flat drumhead, like that of a child's drum, but is shaped like a funnel, or "like an umbrella turned inside out." This shape, its position, and its connection with the hammer, all serve according to certain well-known physical laws to make it particularly adapted to vibrate at any required rate. If you look again at this middle chamber of the ear diagram, you will notice a tube which leads out of it, down to the throat. This is the Eustachian tube, which opens into the throat, and thus gives the middle ear a direct channel to the outer air. This tube is normally closed at its throat (pharynx) end, but is opened every time we swallow. Air is thus let into the middle ear through this tube, and its air chamber is kept full. (If the tube were always open, the sound of our own voices would come to us so loudly as to be quite deafening.) This connection of the ear with the throat has many important effects in health or illness, a familiar one being the slight deafness which frequently accompanies a cold in the head. The Eustachian tube has probably been obstructed by the inflammation of the lining membranes of throat or tube itself. Adenoids in the throat may obstruct the entrance to the tube and thus cause partial deafness.

THE TRUE INSTRUMENT FOR HEARING

When we studied the eye, we found the retina to be the real organ of sight. The true organ of hearing, within which sound vibrations are transformed into nerve messages, is located in and about the cochlea. The cochlea is, as you will see if you look back at the diagram, a spiral tube or canal, not unlike a spiral stairway or the spiral-shaped shell from which it gets its name. Within the cochlea lies a wonderful and complicated structure called after the Italian anatomist who was its discoverer "the organ of Corti." It is a microscopic musical instrument. In a piano when a note is played a certain string vibrates; in the organ of Corti certain rods or fibers vibrate. There are two spiral rows of these tiny rods which slope toward each other and touch at one end in such a way that they make arches. This musical instrument is thus "composed of some four thousand complex arches, increasing regularly in length and diminishing in height from the base to the summit of the cochlea. The waves of sound have been supposed to play on this organ, almost as the fingers of a performer play on the keys of a musical instrument."

Martin says that there are about six thousand inner rods and forty-five hundred outer rods. Just how they work we do not know,

but in some way they catch vibrations and serve as a wonderful apparatus for distinguishing differences in pitch. "According to various estimates that have been made, from six thousand to eleven thousand different tones can be distinguished in the whole range of the ear. The membrane on which the organ of Corti lies is said to consist of twenty-four thousand strands; and fourteen thousand nerve fibers communicate with the hair cells of the organ of Corti." We have come once more into a piling up of numbers, which is a part of the story of all bodily structure, and which

Photos by M. C. Dickerson

YOUNG JACK RABBIT

Rabbits specialize in hearing. Not only have they long, beautiful sensitive ears, but a large part of their brain area is given over to receiving sound messages.

makes possible for each organ its wonderful results, here in the way of tone and pitch. To the marvelous mechanical elaboration of the organs of the inner ear we owe the manifold joys of all musical sounds.

EARS IN THE ANIMAL KINGDOM

To perceive sound a creature must have some sort of receiving apparatus, a living hair or a sensitive tissue, which will take the impact of air or water and vibrate at the same rate, and some transmitting nerve or instrument which will carry the message to some headquarters within. This may not be a conscious headquarters. The sound may simply

start a vibration which will be like the pressing of a trigger to start some movement. But it catches the vibration and makes some use of it. All the higher animals and many lower animals have such organs. Mammals have the most complicated ears. With other backboned animals the different parts are simplified. Only birds have a well-developed cochlea. In most of the lower animals (below the amphibia) the outer and middle ears are lacking, only the inner or true ear remaining.

VARIETY IN SOUND RECEIVERS

The part of the ear which we see, both in human beings and in animals, is chiefly if not wholly for the purpose of collecting sound waves. In man this part of the ear is small and insignificant, a mere flap of skin. But with many of the animals it is highly and variously developed. Think of rabbits, deer, donkeys, horses, and dogs, and you will have at once mental pictures of a variety of "receivers." Man has lost the power to move his ears, except as a small boy sometimes discovers himself gifted above his fellows in ability to "wiggle" his ears. But many of the higher animals depend much on the highly movable ears which they can focus in the direction of the slightest sound. In birds this outer ear is, however, missing. Look at our bird portraits and you will rarely find a visible trace of an ear. The owl has tufts of feathers which might be taken as ears, when in reality they serve to conceal ear openings of unusual size. Ears must be useful to the owl as he betakes himself to his nightly prowlings in the air. Almost noiseless himself in his flight, because of his soft plumage, he must yet take keen account of any betraying sounds of enemy or prey. Hidden away as birds' ears are among the feathers of the head, they are still very well-made ears, with semicircular canals like our own; but the lack of an external sound collector may be taken to indicate that birds depend less on hearing than do some other creatures.

In the kingdom of beasts there are outer ears of all shapes and sizes. Young Jack Rabbit, photographed by Miss Dickerson, has big, sensitive ears as part of his life equipment. He must live by his senses, catching every message of danger that travels across the grass or through the open air. Watch him use them, and you will know that Jack Rabbit prizes his long, beautiful ears.

Cats, dogs, horses, domestic animals and wild animals, hunter and hunted, — all have conspicuous and sensitive outer ears, which they prick up or flick or turn at the slightest sound. No one watching could ever doubt that their ears are a precious part of their sense apparatus. Only a few animals like the elephant ever close them by dropping over-hanging flaps. Eyes may be shut, but the ear is a watchful sentinel, always on guard.

INSECT EARS

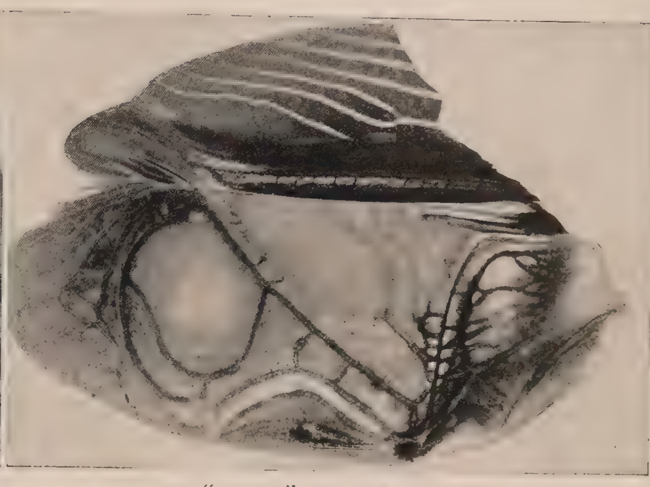
After our discovery of eyes on fingers or toes or anywhere else in the body where they might happen to serve a useful purpose, we shall not be surprised to find ears located with no particular regard to where the creature "heads up." Katydids and crickets carry their ears on their forelegs, each tiny ear consisting of a tympanum or drum, a small liquid-filled vessel to conduct the vibration, and a nerve center with a nerve running to headquarters. Locusts have similar ears at the base of the body.

It is a most satisfying provision of Nature that the insects which are the chief musicians in the insect orchestra have ears with which presumably they can hear their own music. They make sounds — that is, start sound vibrations at certain rates in the air — by rubbing their wings or their legs together, or, in the case of the cicada, by stretching and relaxing tympana or skin membranes; then they manage to pick up, as we have seen, these and similar air vibrations by these hearing membranes on their legs or antennæ. If one makes music by fiddling with one's legs, how appropriate to pick up the sound of it by means of "ears" on one's legs!

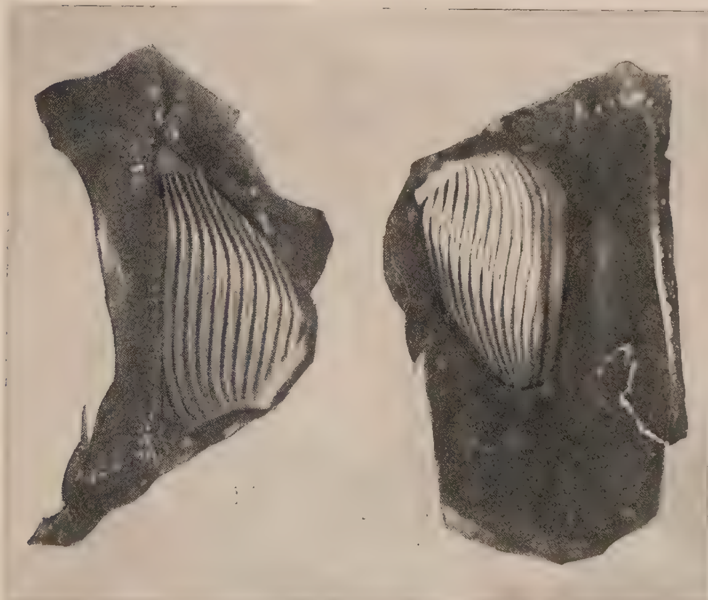
Insect hearing is one of the mysteries into which human beings can hardly enter even in imagination. There seems to be no doubt that insect ears are affected by vibrations which human ears would not hear. As John Burroughs puts it, in the quotation with which this chapter closes, the world of sound with insects may begin where ours leaves off.

HOW INSECTS MAKE MUSIC

THE FIDDLE OF A KATYDID



THE "RIDGED" WING OF A CRICKET



THE TWO DRUMS OF A CICADA

CICADAS, "SEVENTEEN-YEAR LOCUSTS"

INSTRUMENTS OF THE INSECT ORCHESTRA (greatly magnified)

The insects whose shrill calls we hear, the grasshoppers, katydids, and crickets, are not singers, for they have no vocal cords in their throats, to be set in vibration by the air. They are players in an insect orchestra. As a fiddler draws his bow across the strings of his instrument, so they play their sharp, piercing notes by rubbing, two, three or four times a second, one wing upon another, one leg across another, or a leg across the ridges on a wing. See how thick the edges of the katydid's wings are and how the ridges stand out on the wings of both insects.

The cicada plays on two drums. Instead of drumsticks he has in the center of each a muscle with which he stretches or relaxes the skin, "much," says Kellogg, "as a small boy makes music from the bottom of a tin can with a string fastened to its center." The drums are set in sound boxes which some cicadas can open and shut at will, giving a curious rising and falling sound, now loud, now softer.

IN OTHER WORDS

(The following quotation on the wonderland in which insects live is from the last essay written by John Burroughs before his death, entitled "The Pleasures of a Naturalist," and published in *Harper's Magazine* for May, 1921.)

"The insects certainly live in a wonderland of which we have little conception. All our powers are tremendously exaggerated in these little people. Their power makes them acquainted with the inner molecular constitution of matter far more intimately than we can become by our coarse chemical analysis. Our world is agitated by vibrations, coarse and fine, of which our senses can take in only the slower ones. If they exceed three thousand a second, they become too shrill for our ears. It is thought that the world of sound with the insects begins where ours leaves off. The drums and tubes of insects' ears are very minute. What would be to us a continuous sound is to them a series of separate blows. We begin to hear blows as continuous sounds when they amount to about thirty a second. The house-fly has about 4,000 eye lenses; the cabbage butterfly, and the dragon fly, about 17,000; and some species of beetles have 25,000. We cannot begin to think in what an agitated world the insect lives, thrilling and vibrating to a degree that would drive us insane. If we possessed the same microscopic vision, how would the aspect of the world be changed! We might see a puff of smoke as a flock of small blue butterflies, or hear the hum of a mosquito as the blast of a trumpet. On the other hand, so much that disturbs us must escape the insects, because their senses are too fine to take it in. Doubtless they do not hear the thunder or feel the earthquake.

"The insects are much more sensitive to heat and cold than we are, and for reasons. The number of waves in the ether that gives us the sensation of heat is three or four million millions a second. The number of tremors required to produce red light is estimated at 474 million millions a second, and for the production of violet light 699 million millions a second. No doubt insects react to all these different degrees of vibration. Those marvelous instruments called antennæ seem to put them in touch with a world of which we are quite oblivious." — JOHN BURROUGHS.

Photo by E. F. Bigelow

ANTENNÆ OF A MOTH

(Greatly Magnified)

Insects practiced wireless long before man found it out. With antennæ like these for their "receivers" they catch vibrations of the air which are too delicate for human beings to perceive.

OUR SERVANT SMELL

Of smell as chief counselor and prime minister in insect and animal life.

THE sense of smell is so modest and unobtrusive a servant in the routine of human existence that it loses much of the credit which is its due. Particularly as it works with its partner, taste, does it slip into the background. Not until a cold in the head blunts the normal response of the nerves of smell do we recognize the part which smell plays in the pleasure of eating. The taste buds of the mouth may be sampling as painstakingly as ever the different articles of food, but without the contribution of smell we say, "everything tastes alike." To appreciate what smell can and does do on its own initiative, let us first go into the kingdom of the lower animals, where smell is chief counselor and prime minister.

WHERE SMELL LEADS

You have seen two dogs meet and "nose" each other, then pass on without further interest, or set up friendly relations, or attack each other, apparently according to the result of their investigations. You have seen a dog smell carefully a chance caller or an unwelcome tramp, then act accordingly. You have seen a dog put his head down, sniff the ground or city pavement, then start without hesitation on the trail of his absent master. Perhaps you have seen a dog exhibit delight at the smell of a person and have found that the person had a dog at home, the odor of which was evidently carried on the clothes. These are your own private observations and investigations as to the importance of the sense of smell in a dog's life. You did not set about to take them, but as they have come in your way, they will serve as a proof of how high smell may be ranked with animals. It is said to take second place with many creatures, first place with others.

In the world of the honeybee smell seems to lead. Dr. McIndoo, who gave himself to studies and laboratory experiments covering months of time and dealing with hundreds of bees, found that smell was the chief means of recognition among bees. It has always been a question how insects recognized each other, and how males identified females. Sight seemed an unlikely method, as they found each other so readily in the dark. Touch was barred out, for they knew each other before they came together. Smell seemed likely to be and has proved to be the probable mark of identification. Dr. McIndoo's experiments led him much beyond this fact. He came to believe that a bee's sense of smell matched in its importance to the bee our sense of sight; or, to quote his own words, smell "in the lower animals but particularly in the honeybee is so highly developed that we do not have any more conception of it than does the honeybee (if it could think as we do) of our wonderfully developed sense of sight which is able to distinguish accurately the size, form, and color of objects." If any one but a careful and cautious scientist said this, we might consider it a mere opinion. But Dr. McIndoo has studied his bees; he makes no surmises lightly.

HOW BEES WERE STUDIED

One might question how a human being, who cannot get inside a bee and smell as a bee smells, can know much about the bee's sensations. He knows, as you knew about dogs, because bees show their feelings very plainly. If a bee with the wrong odor enters a hive, the other bees do not think to themselves, "That is a queer-smelling fellow," and then tolerantly go about their own affairs. They attack that bee, as promptly as a sentinel challenges a stranger who does not give the proper password. The human observer is left in no doubt as to whether the new bee is welcome or not. When he has tried experiments over and over again, with many hives of bees and under many conditions, and, all other factors being removed, the bee without the accepted odor is attacked, while the bee

which has it is admitted without question, the observer knows fairly well how bees react to the odors of their fellows.

EACH HIVE A SECRET SOCIETY WITH AN ODOR FOR THE PASSWORD

Like human beings and dogs and other animals and insects, each individual bee has an odor of its own. A queen bee has an odor which it passes on to its offspring, a family odor, as it is called. Drones are said to have an odor which is different from that of workers. But, most important of all, each hive has an odor which is distinctive. This hive odor is composed chiefly of the individual odors from all the workers, supplemented by the odor from the queen and the odor from the drones, and modified also by odors from the combs, the frames, and the walls of the hive. Obviously no two hives could have the same odor.

Every single member of a colony, whether worker, queen, or drone, carries on its body the odor of the hive, and this odor serves as the sign by which all the occupants of a hive know one another. A worker bee returning to the hive from the fields passes the guards unmolested because it carries the proper sign, although absence from the hive and the overlaying fragrance of flowers and nectar have made it fainter. Let bees be kept in the open air for three days and they lose all hive odor, and are regarded as strangers if they return to the old hive. When a colony is divided, the hive odor in each half soon changes. It could not but change with half the odors which helped to compose it missing. In three days the workers of the two half-colonies, if reunited, will fight as if they were complete strangers and lifelong enemies, although they have spent their whole lives in the closest association, up to the three days' interval.

Beekeepers have different devices for overcoming the clannishness entailed by a hive odor when they wish to unite colonies or put a new queen into a colony. One is to immerse the bees in a liquid which will somewhat rid them of their hive odor. Another is to add smoke. When a queen is to be put into a foreign hive, the hive is filled with smoke. This confuses the workers, and they fill themselves with honey. By the time they are quiet again and the smoke has disappeared, the new queen has taken on a sufficient amount of their hive odor to protect her.

WHERE SMELL RULES

It is curious to think of bees as so fierce in their insistence on the proper odor of their social life. It is more curious to see how much this odor controls their social life. Dr. McIndoo believes that a normal hive odor serves as the ruling spirit or power in a colony of bees. It seems to be the factor on which their social life depends, on which perhaps it began; without it a colony of bees could not exist. It keeps them together, being a means of preserving the social life of the bees from without, and it rules their relations, the queen odor, which is a part of it, "insuring continuation of the social life within." Workers know their hive mates by the "passport" of odor which they carry; this odor insures a united defense when an enemy attacks the colony. The queen odor constantly informs the workers that their queen is present. The absence of a queen odor in the hive probably explains why the workers in such a queenless colony are irritable and never work normally. With that queen odor they know she is there and that all is well. Her presence means everything to the bees in perpetuating the colony. In one sense it may be not the queen that rules, but this sign of her presence. "Thus by obeying the stimuli of the hive odor and queen odor, and being guided by instinct, a colony of bees perhaps could not want a better ruler."

SCENT MAKERS

When we know how insects depend on odor — and the story of bees might be matched by as elaborate a one concerning ants, while other creatures have not been so fully studied as yet — we wonder what it is that they smell. An insect is a hard-bodied little creature, clothed in armor. A chitin, "shell coat," does not give out secretions as the pores of our soft skins give out perspiration. Insects prove to be little perfume-producing factories, with more or less elaborate glands or tubes, evolved to extract the best elements from the blood to serve as a source of odors and give them forth. As a little

liquid can give forth a great deal of odor, these tiny scent-factories, located at convenient spots on the soft parts of the body, are very economical affairs. There are a great many of the perfume or scent sacs. "According to a recent investigator a drone bee has 2600 olfactory pores, a worker has 2200 pores, and a queen 1800 pores." "Olfactory" is a word which you will like to add to your stock of new words. It is from the root *ol* of a Latin verb "to smell" and the familiar Latin verb *facere*, "to make"; literally, then, it means "making to smell." It is the word used for the nerves and organs of smell, and also for these scent-producing glands.

You have met scent-producing glands before in this book. They were used as instruments of defense by some of the animals. Insects and animals of many species give forth unpleasant odors; the skunk is our most familiar example. Here you meet scent-glands in their more pleasant business of providing recognition marks. How far scent is responsible for many unexplained happenings in the lower kingdoms of life, science has yet to investigate and tell us. There have been remarkable experiments lately in which liberated male insects located females in an amazingly short time across surprising reaches of distance. What part smell had to do with these performances we do not yet know.

WITH FOUR-FOOTED CREATURES

Probably the sense of smell bears a much larger part in the lives of the higher animals than we can even yet realize. No more interesting line of study could be pursued than an investigation of the world of smell inhabited by four-footed creatures of the field and forest, a world to which we with our degenerate human sense of smell are quite indifferent. The cow and the horse, the cat and the mouse, the rabbit, and, leading them all, the bloodhound, could give us important instruction and information.

There is one celebrated experiment which Romanes, the well-known English psychologist and zoölogist, tried many years ago, which should be reported in this connection. He was investigating the sense of smell in dogs. He had a setter which had the most exclusive devotion to him. When he was about, this dog was interested in no one else. On a certain day Romanes collected all the men about the place and directed them to walk close behind one another in Indian file, each man taking pains to place his feet in the footprints of his predecessor. In this procession of twelve men in all, Romanes took the lead, and the gamekeeper brought up the rear. In the absence of his master the dog would always follow the gamekeeper wherever he went on the place.

The procession, with Romanes leading, walked two hundred yards. Then Romanes turned to the right. He was followed by five others. The seventh man in the file turned to the left, and was followed by the other five. The gamekeeper was therefore the last of this second group which turned to the left. All the men of both parties concealed themselves at a distance. The dog was let out of his kennel by a man to whom he was wholly indifferent, and was put on the track of the party. He put his nose to the ground, setter fashion, and ran without hesitation along the track. When he came to the point where the two parties separated, he at first overshot it in his haste. In a moment he returned, *took the track to the right, and found his master*. For the first part of the trail the scent

Photo by Wm. L. and Irene Finley

COYOTE PUP

of Romanes' footsteps had been overlaid by that of eleven others; for the second part of the trail by five others. Also, he was accustomed in his master's absence to follow the trail of the gamekeeper, the last man of the party. But through it all he had no slightest hesitation in detecting the scent of his master and following it. All other scents he disregarded.

WHEN ANIMALS KEEP STILL

William J. Long thinks that the scent of animals is much stronger when they are moving. Here are his observations from his own lifelong study of wild life: "As for their noses, on which they mostly depend for information, I have tried numberless experiments to know how far they can detect a man. With a fair wind, not too strong, blowing in their direction, I have seen deer become alarmed while I was still a full quarter-mile away. On still days, the distance varies from fifty to two hundred yards, according to the amount of moisture in the air. But after a man has been sitting quiet for a time, I am convinced that no animal can smell him beyond a few feet; for the simple reason that, like the animal, he gives off practically no scent while he is motionless. . . . All brooding birds that nest on the ground depend absolutely on this wise provision of Nature."

Photo by Wm. L. Finley and H. T. Bohlman

PETREL WITH NOSTRIL IN TOP OF BILL

THE HUMAN NOSE

They say that the human nose has degenerated, that primitive man used it far more than his civilized descendant and so got much more information from it, and that man used to have a little second nose in the roof of his mouth, as sheep and oxen (herb eaters) do now, but that he lost it from disuse and lack of need of it, so that now only a useless trace of it remains. They say, too, that the nerves of smell which run from the nose to the brain are the only ones running directly to the hemispheres of the brain, the idea apparently being that the brain somehow began with the consciousness of smell. All this is very interesting, but what we wish to know is about our own twentieth-century noses, what they do for us and how they manage the doing of it. Whatever it has lost in rank or power, it is still a wonderful organ to possess.

A FINELY GEARED MACHINE

Our olfactory nerves, tucked away in the upper part of the nose, can with their smelling end-organs do something which no other one of our sense organs can enable us to do. They can get on familiar speaking terms with molecules, or, at least, with substances in such infinitesimally small quantities that the eye would be powerless to see them. It is amazing to think how small may be the particles which are breathed up into the nose, and by contact with the nerve of the organ of smell cause the varied sensations which we experience. When we smell something we are being affected by particles so small that we could never see, hear, or feel them. Open a bottle of peppermint oil in a room and leave it open for a few minutes; its odor will fill the house. Yet delicate scales will show no recordable amount to have departed from the bottle; its weight appears the same. Smell is a "chemical" sense, so-called in distinction from the mechanical senses like touch and hearing. It comes only from a gas or vapor. When we think we smell a liquid we are smelling the vapor arising from it.

The lower part of the nose is concerned chiefly with breathing. Air is drawn in through the nostrils and its main current passes back to the openings into the throat. The olfactory cells

are in the lining of the upper passages, between and a little below the level of the eyes. These cells, which are long, slender, and rodlike, correspond for smelling purposes to the retina's rods and cones for seeing purposes and probably to the rods of Corti in the cochlea of the ear for hearing purposes. They make up the sensitive surface which receives the stimulus for smell and transforms it into the nerve messages which are carried along fibers to the brain. Odors are "sensed" when scent-bearing air within the nose cavity is in motion. Air is brought into the nose both from without, when a person breathes in through the nostrils, and from the throat and mouth, when a person breathes out. The connection with the mouth explains why taste and smell are so closely related.

WHY WE SNIFF

Because the surface sensitive to smell is so high the main current of air does not pass constantly over it. Any reasonably strong odor reaches it in the air as it moves within the nose cavity. But when we wish to detect a faint odor, we "sniff" air into the nose, that is, we widen the nostrils and draw in quick, short breaths, which serve to drive out the air already in the upper nose by drawing in fresh, scent-laden air. We often see a dog or cat raise the head and sniff; they are taking in the freshest of scent-laden air.

A SCALE OF SMELLS

Our human sense of smell is far more delicate than we realize. Scientists who are testing students with smell-concentrating apparatus and a carefully compounded series of smells try them out with three or four hundred separate odors, composed chemically and from natural sources, like flowers, fruits, etc. A Frankfurt professor has gone so far as to make a table of six primary odors, out of which he thinks all smells are compounded, just as the many shades of color come from the primary colors, — red, orange, yellow, green, blue, indigo, violet. The names for such a scale sound odd to us, as we are not accustomed to expressing fragrance in exact terms, but the examples given of each odor call up before our minds very different smell memories.

1. Spicy — as given off from nutmeg, cloves or ginger.
2. Flowery — for which we can furnish from our own memories many examples, but for which he suggests heliotrope.
3. Fruity — as given off from an orange or a lemon.
4. Resinous or balsamic — for which we can furnish pleasanter examples, but for which he gives turpentine.
5. Putrid — for which we need no further suggestion.
6. A sixth, named by a formidable word, empyreumatic, which might frighten us off as too scientific if we could not look it up in the dictionary and find it comes from the word describing "a live coal covered with ashes." It means "smoky" and is matched up by the familiar and certainly distinctive example of the smell of burning leaves, or, perhaps, of hot tar.

Please notice that we are not saying that this *is* the primary scale of odors. Many men may propose many scales before an accepted scale is given out. But Professor Henning bases this list on 2747 tests, and certainly none of us are wise enough to say him nay.

SMELL AS A FOOD SENTINEL

Nature is very particular about what goes into the food laboratories. What we see or hear or smell or even touch may be most unpleasant, but it is outside of ourselves. By closing eyes, ears, or nostrils, or by drawing away from it, we can protect ourselves from it. But if anything harmful gets into the food factories of the stomach and the other internal organs of the body, it is in a position to do us great harm without the possibility of swift relief. So Nature has guarded the entrance of food by four of the five special senses—by sight, taste, touch, and smell. Past these sentinels it must go before it can enter the inner chambers of the food factory. Of the four, taste and smell play by far the more important parts, and smell leads off in a way surprising to any one who has not made actual tests. Sight and smell are the long-distance "food detectors." We see an article of food and we smell it long before it touches the

lips or tongue. Many animals locate their food primarily by this long-distance sense of smell. But even after it has passed this test and been permitted to enter the mouth, smell is essential to our pleasure in it.

We have cited the familiar experience of finding food tasteless when one has a cold in the head. The sense of smell is very easily fatigued; as soon as a strong smell in a room becomes familiar we cease to notice it. It is also easily blunted by any inflammation of the lining membranes of the nose. There are also unfortunate persons who are wholly without the sense of smell. Dr. Patrick, experimenting with such a person, found that blindfolded she was unable to identify by their taste the following substances: "vanilla extract, pineapple syrup, banana, grape, quince, strawberry, tea, chocolate, sour milk, kerosene, claret, rhubarb, onion, eggs, and boiled turnips. The results suggest that these substances, although they seem to have very characteristic tastes, are actually differentiated and recognized on the basis of their olfactory rather than their gustatory [taste] or tactual [touch] qualities."

Such experiments, of which there have been many in recent years, combined with our own experience, bear out the accepted estimate of smell as a faithful but most self-sacrificing servant. It is good for us to have this pointed out to us so that we may give smell more honor in our thoughts.

OUR SERVANT TASTE

Of taste, and its contribution to our lives.

THE value of one member of a household of servants is likely to appear when he is absent. Then the head of the house discovers, sometimes for the first time, what part that particular servant took in the smooth running of the domestic machinery. It is enlightening to consider what would be missing from our comfort and good health if taste was absent or refused to work.

IF TASTE WENT OUT ON STRIKE

In the first place, the pleasure of eating would disappear, particularly if, as would certainly happen, taste's silent partner smell went on a sympathetic strike. How smell would behave if it should stay on duty with taste absent, it is hard to predict. Undoubtedly smell contributes more to the fine flavors and the delicate discriminations between foods than does taste; but taste supplies the basal facts concerning whether food is bitter, sweet, acid, or salt. We might eat without sampling our food by taste. We might have food put through to the stomach as it is ground through a meat chopper, with no resulting sensation; but eating would be a stupid process. As food is absolutely essential for the running of the machinery of the body, Nature is wise in making the process of eating pleasant.

In the second place, the act of tasting sets off the process of digestion. If taste were missing, digestion would not be properly started, and the whole household would be upset. Experiments go to prove this. There is the well-known example of dogs kept by Pavlow in his Petrograd laboratory, upon whose stomach reactions he was able by ingenious devices to make accurate observations. These dogs were kept as pets; they had all the usual satisfactions of dog life. They were fed, as might happen with dogs outside a laboratory as well as dogs within one, food which they liked, food to which they were more or less indifferent, and food which they would only eat when they were very hungry because it was not their choice of diet. It was proved beyond any question that the moment they tasted food which they liked the flow of gastric juice in the stomach started well. When they were indifferent, or displeased, or excited from some outside cause, and did not welcome their food, the flow was not so great. Dr. Carlson in Chicago has proved the same facts with men under his observation, one in particular a healthy young man who, because of an
to the lower throat, had had for

practice artificial feeding, which was as natural therefore to him as it is for you or me to eat normally. Yet because of this injury his digestion processes could be observed. If this man chewed some indifferent substance, like rubber, which had no taste, there was no flow of gastric juice in the stomach. Eating bread and butter produced a smaller flow than chewing meat; the eating of fruits which he liked and of sweet desserts produced a greater and more rapid flow. These and a great many other experiments on many persons go to prove that it is taste, pleasurable taste at that, which starts the gastric juices flowing and sets up the whole train of digestive processes in the stomach. Taste is the servant that opens the front door and ushers in food. If taste approves and welcomes the food, it sends the message to the household to prepare for the new arrival.

The third function of taste belongs more to the lower animals than to man in the present habits of his civilized life. This is the use of taste as a guide to what we shall eat, and a sentinel to keep out injurious substances. The beasts of the field depend on taste for such sentinel duty. For us it is not so reliable a guide. Poison may have a pleasant taste which would not lead to its rejection, and excellent food may be rejected if its taste does not happen to please. We shall discuss later our responsibility for training this taste servant of ours so that it will perform wisely and well its duty of welcoming cordially all good foods. But that lies in the province of master or mistress. It is for us to consider here the physical basis of taste.

MAPPING THE TONGUE

Taste buds, with groups of taste cells folded in an envelope of protecting and supporting cells, are located chiefly on the tongue, but also on the soft palate and sometimes elsewhere on the lining of the mouth. They are the end-organs of taste, and within each are usually found from ten tc sixteen taste cells. Around these taste cells wind nerves which take the taste message to the brain. There may also be taste cells scattered about on the tongue, outside these taste buds, and there may be free nerve endings for taste sensation in the mouth. On these points science is not yet ready to speak with any finality. But one interesting thing it has done; it has given us a map of the tongue.

There are four main tastes, others being a blending of these four, namely, sweet, salt, sour (acid), and bitter. The surprising fact is that the susceptibility to these tastes is not equally distributed over the whole tongue, but that it is possible to make a regular geography map of the tongue with tastes for continents and tasteless spaces for oceans. At the front or tip of the tongue lies the sweet-tasting area; at the back of the tongue the bitter region, and at the sides or edges the salt and the acid. In adults the center of the tongue seems to yield no taste sensations; in children the taste buds are all over the tongue and in the soft parts of the mouth lining. Roll your candy, therefore, on the tip of the tongue, for getting the best of its sweetness; swallow your bitter medicine as fast as you can, so that it will not be detained at the back of the tongue; and chew your food well so that it will be rolled around the sides and sampled by the sour taste areas. Thus you will get the full benefits of your taste organs.

None of these tastes can be perceived if the tongue is wiped dry. This you can prove for yourself by drying the tongue thoroughly and then putting a lump of sugar on the tip. Not until the sugar begins to dissolve through the flow of liquid saliva in the mouth will there be any sensation of sweetness. In order to be tasted, a substance must either enter the mouth in liquid or fluid form or else it must be dissolved in the saliva. The taste organs require a fluid to stimulate them.

Taste is easily fatigued. After one has eaten a considerable amount of any substance, particularly of sweets or a highly flavored food, the taste is not so strong. A small amount of such food is better appreciated than a greater quantity. It is a wise provision that many of the staple articles of diet—bread, potato, oatmeal —are comparatively tasteless, else we should weary of them in the quantities necessary for our proper nourishment. A spoonful of pickle or of rich jelly is sufficient for our satisfaction.

TASTE A CHEMICAL SENSE

Taste is grouped with smell as a chemical sense because it is aroused by a chemical rather than

by a mechanical stimulation. Both taste and smell involve a chemical response or action in the cells which they affect, which is very different from the mechanical effect on the eardrum of the beating upon it of air waves or the pressure exerted on any part of the body by touch. The tongue is susceptible to touch sensations and to temperature sensations, which work along with taste in producing our impressions of the food eaten. The so-called taste of ice cream is a taste of the sweet ingredients mingled with sensations of cold and smoothness. A liquid may be so hot that all we get at the first moment of taking it into the mouth is a sensation of heat.

An interesting observation on the way touch sensation may be confused with or mistaken for taste was made in one of the government offices on certain roots or plants which burn in the mouth with a most acrid and irritating taste. The Indian turnip or jack-in-the-pulpit root gives a most bitter and irritating sensation when taken into the mouth by mistake. When it was put under the microscope, the observer could plainly see that it was driving minute sharp crystals into the tongue. Bundles of crystals served as the guns for this bombardment, and slender arrows of calcium oxalate were the missiles discharged. No wonder the tongue was irritated and sent messages of distress to the brain under such an attack. It was as if a thousand pin pricks were being "tasted." But when that same root was pulverized, so that it was a fine powder like flour, the acrid "taste" had wholly disappeared. It was not a "taste" at all, but a touch sensation of unusual violence.

It has been suggested that the taste sense was originally a modification of the touch sense. It is one of the earliest senses to appear in the lower kingdom of life, and is said to be more perfectly developed at birth in the human child than any other sense. Working with its partner smell, it is certainly valuable both in its physiological effects on the body and in its mental results of satisfaction. If, when we study our food life, we find that we are not appreciating it or are training it badly, we shall have to take ourselves in hand to prove ourselves worthy masters of so capable and faithful a servant.

A MAN WITH ONLY TWO SENSES

Of a Canadian soldier, as reported in the "London Lancet," who had only sight and hearing for his sense equipment, and of the senses as they may be ranked and grouped.

MOST persons have five senses of which they are aware,—sight, hearing, taste, touch, and smell,—and several others on which they depend without knowing much about them, like muscle pressure, sense of balance, and temperature sense. During the war there came under the observation of British army doctors a man who had lived a comfortable life up to the age of thirty-seven years depending only on the two senses of sight and hearing. He was a Canadian soldier who had been in the army for two years and was sent to the hospital by an attack of mumps. There it was found that he was practically without the "body senses," and had of the "head senses," which we have been discussing, only the two. He was neither ill nor imbecile. He was a well-developed, powerful-looking man, of a cheerful, even temperament, highly good-natured, mentally rather above the average of intelligence. Let us see what he lacked in order to get an idea of what we who are normal possess.

NO SENSE OF TOUCH

There was complete absence over the whole skin surface of the sense of touch. If a poker was dropped on his foot, his head, or his side, while his eyes were closed, he did not even know he had been touched. He did not feel the ground when he put his foot down. This made it hard for him to walk at night. He told how his inability to bring his heels together without controlling the movement with his eyes had frequently led him into trouble with his superior officers at drill. He could not be sure of putting

his heels together with his "eyes to the front." He could not recognize an object placed in his hand unless he could look at it. The touch sense, by which we recognize pressure on the skin, and are made aware of the degree of pressure, how strongly applied, and of the kind of pressure, whether by a soft object or a hard, a rough object or a smooth, was missing. His skin might as well have been a leather coat for all the sensation it gave him.

NO MUSCLE SENSE

Muscle sense is, like sense of balance, an intimate sense of ourselves. It does not, like the five leading senses, tell us of the world about us, but of our own bodies. It is only within recent years that it has been recognized as a special and separate sense. When we see what this man could not do because he was without muscle sense, we shall see that it has very good claim to a place on the list. With his eyes closed he could not tell anything about the position of parts of his body. He could not tell whether his arms were moving or still. If his limbs were moved when he was blindfolded, he would exhibit genuine surprise at their positions when he saw where they were. If his eyes were open and he could see to move his arms or legs, he could move them as well and quickly as you or I. But he did it as we should move an object on a table from one spot to another. If his eyes were closed and he were asked to make any movement with his arms, the choice of what he should do being left to him, he could not do it. He could not clasp his hands together, or touch the tip of his nose with his finger when so directed.

HE FELT NO PAIN

Perhaps when you have had a headache or a toothache you would have liked to be free of the sense of pain. There are times when that would seem desirable. But in the long run it would be very far from desirable. Pain is one of the most useful of the body servants, for it gives warning that something is wrong and locates with fair accuracy the place of the disturbance. It is a very unobtrusive member of the household, for it never appears when things are going well. But like an automatic fire alarm it gives prompt notice of danger. This soldier had no sense of pain. His body was covered with scars of wounds and burns which he had inflicted on himself to astonish onlookers. The doctor who reported his case said that he had himself seen him on more than one occasion hold a burning match against the skin of his arm for ten or fifteen seconds, and then unconcernedly pick off the charred surface skin. If he did not happen to look down and see what was occurring he might have been bitten by a rattlesnake and never known it. The prompt measures to get the poison out of his system would not be put into effect, for he would not know from any pain in the spot that he had been bitten. Any internal illness might proceed far before it would be discovered. We should be in grave danger if we lost all sense of pain.

HOT AND COLD ALIKE TO HIM

He had no sense of temperature. The faculty, or faculties, of perceiving cold and warmth have lately been given a separate place in the list of sensations. The organ for temperature sense is the whole surface of the outer skin and parts of the skin of mouth, nose, and throat. This man knew no difference between a hot dinner and a cold lunch, a summer day or a winter day. A soda fountain would have had no charms for him on a hot day, nor a cup of hot soup with the thermometer below zero.

TASTE AND SMELL MISSING

Taste and smell were absent from his experience. With eyes closed he was equally ready to eat sugar, salt, pepper, or mustard, cooked food or raw meat. On one occasion he was found to have eaten a lump of bath brick (used for cleaning metal) about the size of a hen's egg, which a hospital orderly had left in his way. But the delights of a "tasty" meal had never been his.

RANKING THE SENSES

Stories of Laura Bridgman, Helen Keller, and others have made us more or less familiar with the condition of a person who lacks the

leading senses of sight and hearing. Helen Keller has shown us how much touch and smell may give back to a person trained to respond to them. Here is the case of a person who depends almost wholly on the two senses which blind and deaf persons lack. If we had never ranked the senses in their contribution to physical and mental well-being, we should be led to rank them now. Possessing sight and hearing, though without most of the lower senses, this man leads a fairly normal life. No one of us would be willing to experience his deprivations in the way of taste, smell, touch, sense of temperature, etc. His world lacks much that makes life precious and satisfying. But in his activities and in his contact with other people he can be fairly normal; while a person who is both blind and deaf, though possessing the other senses, is pitifully handicapped so far as any free life is concerned, and is shut into a dark, silent, limited world.

GROUPING THE SENSES

There have been several ways of grouping the senses, each of which suggests some interesting fact about them.

One way is as body senses and head senses. This grouping has to do partly with the position of their end-organs, partly with the headquarters to which they first send their messages. Body senses include touch, pain, muscle sense, and those other groups of sensation received for the most part in regions of the body other than the head. These messages are sent to the brain by the route of the spinal cord. Head senses, like sight, hearing, taste, and smell, have their end-organs in the head and send messages directly to the brain or midbrain.

Another rather similar grouping has special senses and general senses, the special senses being the original five as we learned them in childhood, each having its own particular end-organ, the eye for seeing, the ear for hearing, the mouth for tasting, etc.; while the general senses, like pain and muscle sense, are distributed over the body and may or may not have their own particular end-organ. At any rate it is not so specialized as to be easily discernible.

One grouping is as internal senses and external senses. The receiving or end-organs of the internal senses lie within the body and tell of the condition of the body, pain, muscle sense, equilibrium sense, hunger, thirst, temperature sense; the receiving organs of the external senses lie on the surface of the body and tell of the world without the body. Some of the latter are contact senses, requiring direct contact with the object in question, like touch and taste; others are projecting senses, like hearing and sight, which tell of things not immediately touching the body.

To the familiar five senses, modern scientists ask us to add sense of balance, muscle sense, hunger and thirst, pain, and temperature sense. This makes ten in all, eleven if hunger and thirst are counted separately, as they more often are. Helen Keller, lacking the two which we should rank at the top, has created for herself such a wonderful contact with and appreciation of the world that we forget how imprisoned she is. Our Canadian soldier, having those two senses but with most of the rest crossed off, at least so far as his consciousness is concerned, passes a comfortable and cheerful existence. But most of us cannot spare a single one of the eleven. Let us not grow indifferent to our faculties and our blessings, but use them to their utmost, always eager for every message these faithful servants bring us.

Photo by R. W. Shufeldt

FACE OF A LIVING BLUE CRAB

A STUDY IN FACES

Where sense organs come together — a picture study of faces in series—front-faced and side-faced, hunters and hunted.

FACES came into being when a group of sense organs set up shop together instead of being scattered all over the body. The mouth began it by taking its place at the front end of the body. Amœba did not have any specialized mouth in its one-celled body. It took in food at any point where food appeared and rolled its jelly-like form in any direction. But when creatures began to go after their food "in a fore-and-aft direction," as Dr. Gregory has put it, that was the first step toward the making of a face. Eyes and nose set up a partnership with the mouth; ears obtained a convenient location near by; and when the brain coöperated by pushing out a forehead, the elements of the human face had appeared, and were ready for shaping together into a unified whole.

"FEEDING THE FACE"

When we go back to beginnings, the slang description of eating as "feeding the face" is not far wrong. The oldest part of the face is the mouth, and the first business of the face is to

Photo by R. W. Shufeldt

FACE OF THE GILA MONSTER, A LIZARD

From W. Saville Kent
FRONT VIEW OF COFFER FISH

Photo by L. W. Brownell
YOUNG NIGHT HERON SHOWING ANGER

direct the mouth toward food. Among some of the anemones and corals there is found a well-developed mouth, surrounded by sensory organs, tentacles. With food getting the creature's first business in life, it became convenient to have eyes, that is, spots and nerves sensitive to light and shade, up at this front end of the creature near the mouth. They might be of service in food perceiving. Flatworms have this arrangement. Next comes along a wormlike creature (*Peripatus*) which has little tubercles on the skin equipped with hooks to pull food into the mouth, and some paired limblike structures behind the mouth. Now we are beginning, as the children say, "to get warm." Insects, and lobsters, crabs, shrimps, and similar water creatures, begin to have what really look like and serve as faces. There are jaws for the mouth, jaws which do powerful work, as we saw when we studied "mouths that catch food," and paired sense organs on either side, and in some insects a tough skin covering.

We have to go to the backboned creatures, to the shark, to find the first face that has all the elements of a face as we know it. Here are nostrils, eyes, mouth, tongue, and lips, the whole covered by a tough skin; in certain sharks there are teeth that seem to be formed from skin. The shark's face is still a food-getting partnership. Mouth, tongue, and lips must be brought in contact with food. The organs of locomotion must therefore be controlled to bring the mouth up to the food. Eyes and nose exist for the purpose of directing this locomotive apparatus toward the article of food desired, — usually a living prey. Breathing, which is for fishes a process of taking oxygen from the water, requires gills, and these gills are supported by arches which are important in the development of jaws. A shark face is not to our thought beautiful or successful in expressing emotion or intelligence. Those are qualities we expect of a face. But the shark would tell you that is not the purpose of a face at all, according to his way of living; a face is a convenient food-getting partnership. As such it serves him well.

WHEN FACIAL MUSCLES APPEAR

Our pictures carry us another step up in the series of faces, showing the face of the lizard, with its mask of scaly skin. All reptiles have this type of face with a stiff covering, immobile,

expressionless, without a possibility of change. Birds, too, have immobile faces, with stiff, horny beak or bill. Only the bright eyes can give much expression to such a face. But when we come to mammals, the covering becomes soft and flexible. The lips, and the skin about nose, eyes, forehead, and ears are all flexible, all controlled by muscles which can pull them this way and that. Now for the first time we come to faces capable of varieties of expression. For some the limits of variation are few in the way or change of expression; but there are great possibilities in this flexibility. They receive their

Photo by Wm. L. Finley and H. T. Bohlman

PORTRAIT OF WESTERN GREBE

highest fulfillment in the wonderful, sensitive, mobile face of man.

BIRDS HAVE SIDE EYES

As we studied the eyes of living creatures, we postponed a most interesting and important feature of vision, the position of eyes in the higher animals. After eyes had ceased roaming about the body and being carried on finger-tips or legs, as suited the creature's convenience, and were located with other sense organs in a face, there were still possibilities as to how the face should be shaped and where the eyes should be located. In a bird face an inch or a half inch to right or left may make all the difference in the world as to whether the bird can see in the directions in which it needs to see. Dr. Beebe

Photo by Wm. L. and Irene Finley

SIDE VIEW OF SNOWY OWL

discusses this well. The eyes of most birds are placed, he says, at the sides of the head, in such a position that the bird cannot bring them to bear simultaneously upon the same object, but is compelled to turn its head and look sideways. "As birds spend so much time in the air or in trees, where danger may threaten from all sides, above or below, this arrangement is most useful to them, giving them command of almost their whole surroundings, whereas, without turning the head, we can see only ahead of us. In much the same relative position the two ears are placed, and the absence of a directive outer ear renders the bird susceptible to sounds coming from every direction."

Photo by Wm. L. Finley and H. T. Bohlman

PROFILE VIEW OF CALIFORNIA CONDOR

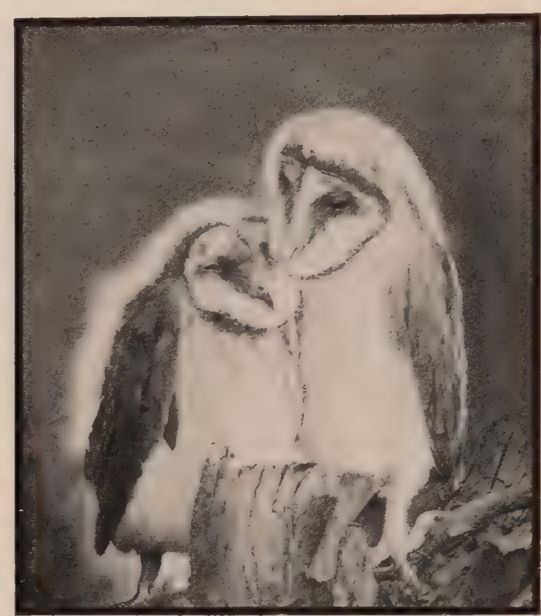


Photo by Wm. L. Finley

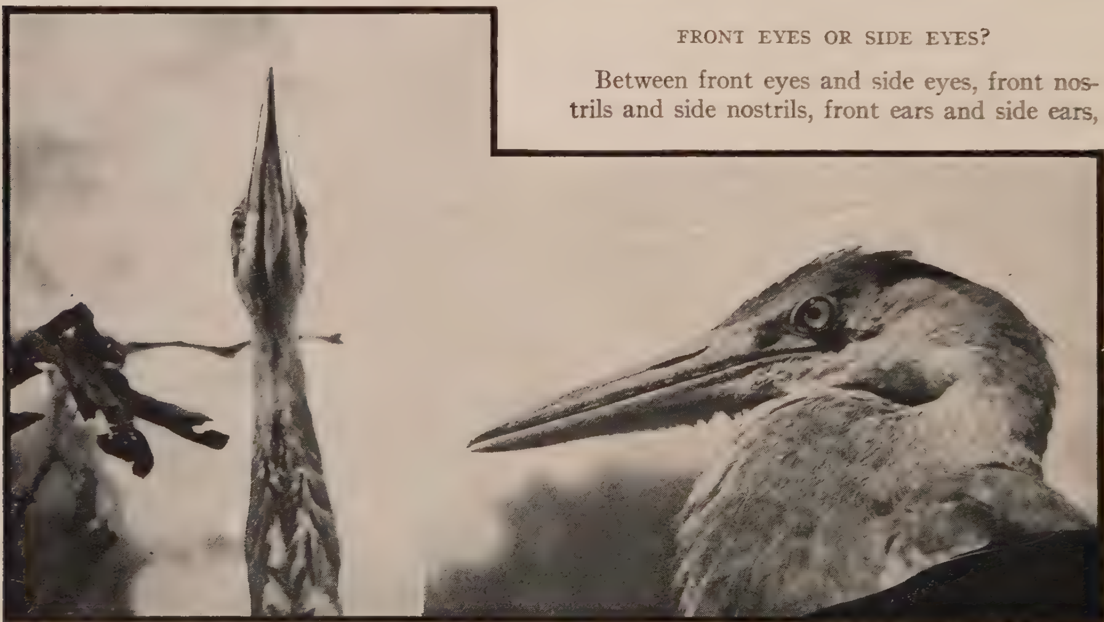
YOUNG BARN OWLS

Owls are the exception to this custom. "Living most of their active life at night, always pursuers, these raptorial birds have few enemies to fear. Their subsistence depends upon the keenness of their senses when focused in one direction, downward. When its strong, soft-feathered pinions carry a mousing owl over field and stubble, the head, like the nose of the hound, is held low, and that not a rustle nor a motion of the little field mice may be lost, ear openings are turned downward and the eyes look full upon the ground. Look a barn owl in the face and you will see the entire circumference of both eyes, but a dove, one of the pursued in life's race, shows in the front view only the profile of the eyeballs."

Mr. Finley's remarkable pair of photographs of a heron's head show how in a profile view the bird would seem simply side-eyed, with no other angle of vision, but how the shape of the head and the protrusion of the eyes make direct downward vision possible. The left-hand picture was taken directly below the head. Without bending the neck the heron is looking downward, while at the same time commanding a wide horizon view to right and left. By catching this picture for us, Mr. Finley has proved to us what otherwise we should find it difficult to appreciate.

FRONT EYES OR SIDE EYES?

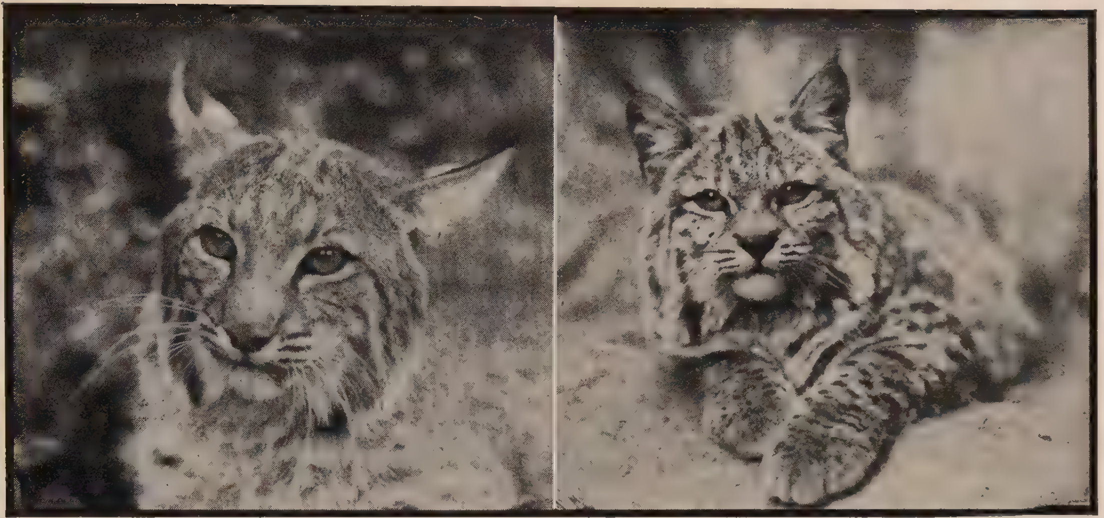
Between front eyes and side eyes, front nostrils and side nostrils, front ears and side ears,



Photos by Wm. L. Finley and H. T. Bohlman

HEAD OF GREAT BLUE HERON (FROM BELOW), AND A SIDE VIEW

The eyes are so placed on the lower sloping sides of the head that, as Mr. Finley puts it, "the bird can stand like an old stump in the water and see a minnow swim past without a side turn of the head."



Photos by Wm. L. and Irene Finley

THE BOBCAT — A HUNTER WITH FRONT EYES

it is possible to draw a long dividing line. When this is done and the animal world is ranged along either side of it, a most interesting situation will appear. On one side of the line will be grouped the hunted members of the animal kingdom; on the other side the hunters. Front eyes are the hunters,— the dog, the cat, the fox, the wolf, the lion, the bear, the tiger, the leopard. Side eyes are the hunted,— the mouse, the rabbit, the antelope, the deer, the squirrel. Birds, except the owl, are the chief exceptions to this rule. Even the hunting birds, like hawks, have side eyes, but, as Mr. Brearley has pointed out, "they sight their quarry from a height, and need a wide range." The average hunter peers straight ahead for his prey. He is strong enough to pay little heed to any other creature that may be prowling about. But with the hunted it is another story — the hunted are alert for every sight or sound or odor which may tell them of a pursuing enemy. They want eyes that look in opposite directions to warn them of approaching

Photos by Wm. L. and Irene Finley

A KANGAROO RAT AND A CONY — THE HUNTED WITH SIDE EYES

foes; they also want to get from the passing breeze any hint of moving life in their vicinity. The dog, a hunter, is a meat eater; he hunts by means of scent and depends much on his front nostrils. The hunted animal is more likely to be a vegetarian, living on plant products, which are not difficult to locate.

Ears conform somewhat to this general rule, but not so accurately as eyes and nostrils, for is nearer the rear. The elephant, which has the largest pair of ears to be found in the animal kingdom, is side-eared; but he has great flaps which he can extend. With them spread he is front-eared, ready to catch any sound from the front. They do not cover his ear opening, as do the bloodhound's ear flaps, but reinforce his hearing, as a man holds his hand behind his ear to catch sound better.

Photo by E. R. Sanborn, New York Zoological Society

HEAD OF NUBIAN GIRAFFE, A LONG-FACED ANIMAL

Note the length of the head as compared with the man's wrist and hand, also the length of the tongue as it is partly out of the mouth.

they can be flicked from front to side. This power to move the ears, which man lacks, is a valuable asset to many animals. Mr. Brearley cites familiar instances of this power. The horse, once a hunted creature, is side-eared when at rest. His ears naturally open sideways instead of nearly forward, as do the cat's. At the slightest sound in front, he will prick them forward in a flash. If you speak to him in driving, he will turn them so that the opening

Man is front-eyed, but his long narrow eyes afford a considerable side view. Also, as you will remember, he can turn his eyes more than most animals, which must move the whole head. Only the chameleon and some other creatures can "roll their eyes" as man can. Man is front-nosed. His ear arrangement, which he shares with apes and monkeys, is a clever combination of both features. "He is front-eared," says Mr. Brearley, "in that his ears stand out

ALWAYS ON GUARD

Photos by Wm. L. and Irene Finley

YOUNG ANTELOPE

Note the eyes on either side of the face yet so placed as to appear in the front view, the long sensitive ears, and the expression of alert attention.

somewhat from the sides of his head and that the rim and bowl-like hollow are so shaped as to intercept sound waves coming from the front, and side-eared in that the greatest surface is presented sideways."

A FACE ON TOP OF THE HEAD

When eyes, nose, and mouth came together, there were still all sorts of possibilities in the shape of the head which should hold them and the part of the head's surface where they should locate. The hippopotamus has a convenient arrangement for comfort in his leisure hours, between meals. An air breather, he still likes to spend much time in the water. Eyes, ears, and nostrils are crowded together at the top of his head. He can lie almost under water and yet have all three just barely above the surface. His air-breathing nose and his food-taking mouth do not connect as do ours; so he can open his mouth under water and have eyes, ears, and nose open to the air above. Alligators and crocodiles are among the animals which can do this combination "stunt."

LONG-FACED OR SHORT-FACED

Did you ever stop to think, by the way, that most animals must thrust their noses into their food in eating? Man's nose is conveniently ridged and lifted so that this can be avoided. The pig has no such delicacy but sticks his snout right into the mess of food. When the mouth is a food-getting implement, it must be advanced in front of the face, and especially of the eyes. Hence this long snout of the pig and many other animals. Grazing animals like the cow carry the food-getting mouth far ahead of the eyes. But the more the fore limbs are used in getting food, the more the mouth is relieved of this duty, the less need of a long snout. Compare the long-faced cow and the short-faced squirrel which uses forepaws to hold food and convey it to the mouth. Mr. Wood-Jones, who calls our attention to this distinction, suggests also that carnivorous animals which kill with the mouth have long faces, while those which kill with mouth and paws may have shorter. He gives as familiar examples the long-faced dog (originally from the wolf family), which grasps and kills with his mouth, and the shorter-faced cat, which holds food in the forepaws and kills with either paws or mouth. The tiger (of the cat family) has the snout region shortened. It kills with the fore limbs and holds its victim with the paws. Such distinctions may be carried too far, but they are interesting and they hold good in many if not all cases. With these ideas in mind we can make up quite an accurate story of the life of a creature by studying his face.

THE HUMAN FACE

The three most conspicuous features of the human face are the pushing forward of the forehead, the drawing back of the jaws so that they are beneath the forehead in a direct line, and the development of a chin. Man has a forward-looking face. His brain case is large, and this has made the high forehead, which is different from that of any of the animals. Man has a strong, expressive chin, which animals lack.

A WORLD OF IDEAS

Some persons, when they study man in comparison with the lower animals, are so strongly impressed with his likeness to them that it overshadows everything else. There is a whole school of study and writing on that line. Physically, to be sure, man has an animal body. In this study of the senses we have been interested to see how man shares with the animals the organs of sense, though his are in general far more developed. But while we are dwelling with interest on the likenesses of structure which make us understand better the lower kingdoms of life, we must not be deceived by them into rating animal life on a par with our own. We must not fall into the mistake of interpreting the activities of simpler animals, as Professor Parker has well put it, "as though these creatures were miniature human beings."

A creature reacts to the stimulus applied to a sense organ as a gun reacts to the pulling of the trigger. As we go higher in the animal world, if two sensations are present, one may overtop the other, and the creature react to the more important. But an animal is still, if we may try to put it in words, at the mercy of his senses. He lives in a world of sense, and his reactions

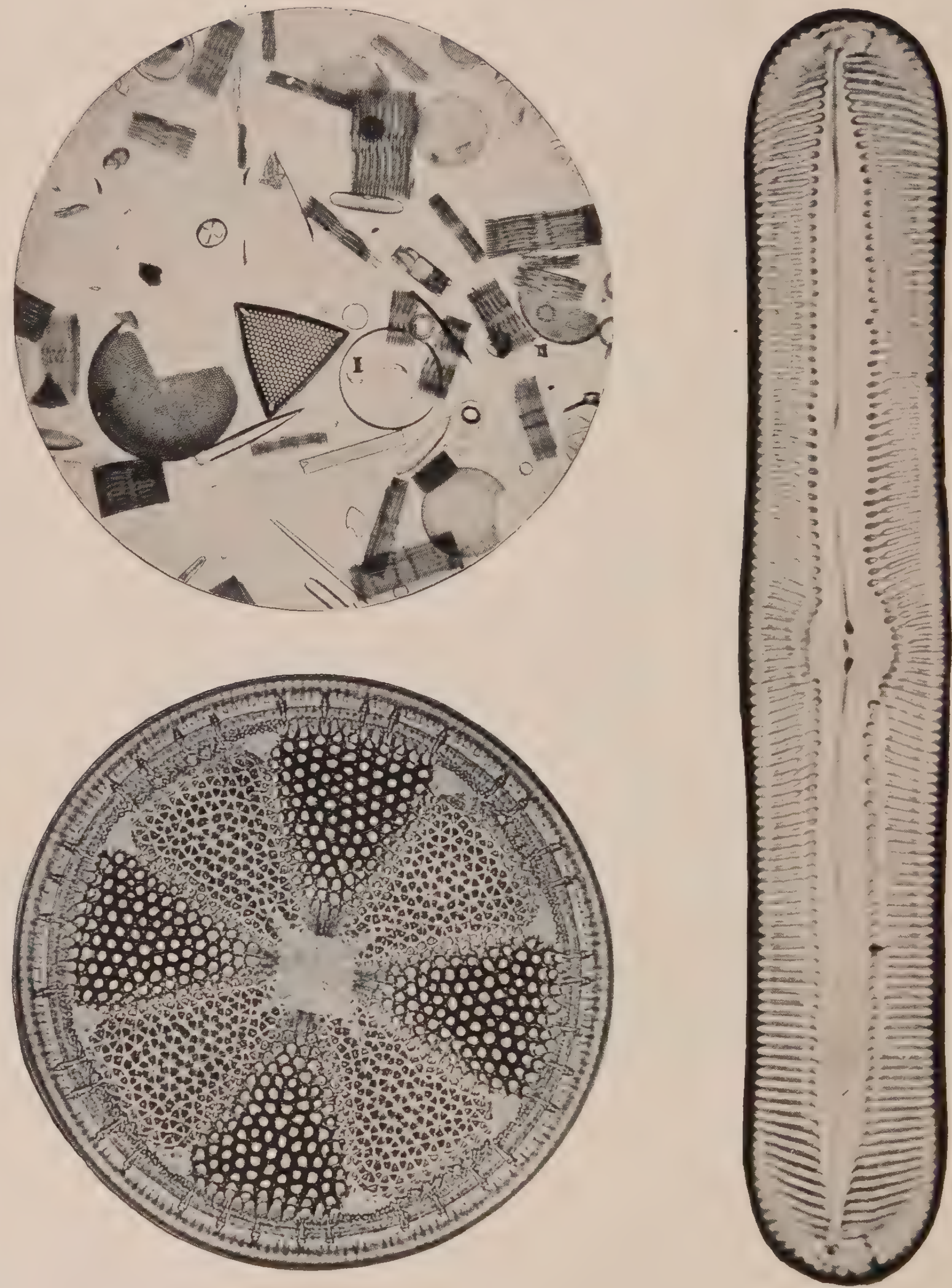
are chiefly to it. With man it is different. Man is endowed with high mental powers. He depends on the world of sense but is not ruled by it. A student absorbed in his books "does not hear" until a sound is very near and loud. "A man may walk along city streets, his eyes and ears bombarded with brilliant lights and loud sounds, and yet the center of his consciousness may be a train of ideas." The world of sense presents its messages, but his attention is elsewhere. "While ideas are probably present to some extent in the minds of the higher mammals, they are hardly so far freed from connection with external stimuli that the animal can shut out the world of sense from its consciousness and dwell in a world of ideas." While we rejoice in all our elaborate apparatus which supplies us with a world of sense, we should never forget that our crowning glory is that we have our real life in a world of ideas. Our senses are our servants, not our masters.

Photo by Wm. L. and Irene Finley

MARTEN IN TREE

At attention, with every sense keyed to quick response to the messages of his world.

GLASS HOUSES BUILT BY PLANTS



Photos by Philip O. Gravelle

DIATOMS — THE JEWELS OF THE PLANT WORLD

They float in water and are so infinitesimally small that they slip through between the meshes of the finest silk; yet they are so perfect in design that they are used as test objects for determining the perfection of the lenses of microscopes. At the top, left, is shown a group of strewn diatoms, magnified about one hundred times. The other two are single diatoms, greatly enlarged to show their designs. (See page 234.)

Photo by Wm. L. Finley and H. T. Bohlman

CHICK OF WESTERN GREBE, WITH LEGS AT END OF BODY, AN EXPERT SWIMMER

IN LIFE'S WORKSHOPS

Life as master manager of enormous groups of workers — life as miracle worker building islands out of sea water.

LIFE is always at work. It creates daily and hourly the wonder world in which we live. Yet no one has ever seen life. The reason for this is simple. Life never stands out alone. On this earth, at least, it is always working through matter. While we, with our earth-eyes and earth-bodies, can see the matter through which it works, — the green grass, the blossoming plant, the moving animal, — we cannot look through and beyond and within to see the force that is doing the work.

HOW DOES LIFE WORK?

The only way, then, for us to get really acquainted with life as a working force is to go into its workshops and see what is being accomplished. And while we may not see life, we shall come so near that we shall feel its breath on our cheeks and its whisper in our ears. We shall sense it as a presence and an active force. How shall we think of life as the invisible workman of the world? One way is by a sort of Jack-and-Jill picture, life pushing matter uphill, matter always slipping back downhill. Can you not see the picture? Dull, heavy matter, the stuff of which mountains and houses and dirt and water are made, slipping and sliding down the slope, and life, agile, lively, darting through matter, pushing, pulling, hauling, tugging it triumphantly up the hill. Another way is to think of life as a current, running through matter even as an electric current is sent on wires through a house. We cannot see the electricity; yet we can see the light that flashes out when we have pushed the button. So life runs through a dry, brown seed, and shortly we see a living, growing plant. Let us make sure that as we look upon the wonders of life's handiwork we do not forget the marvelous, mysterious, unseen force which is back of them all.

LIFE A MASTER MANAGER

Life has a unit machine, the cell. This machine is so small that it is below the range of vision of the unaided eye. Yet within it dwells

the power of life. Sometimes, in some species, a cell lives a solitary life, working out its salvation alone, unaided by its fellows of the same family. The amœba is such a one-celled animal; the diatom, of which the chapter immediately following this one tells, is a one-celled plant. But in all higher forms of life cells are combined. Life is a past-master in teamwork. It masses hundreds and thousands of cells as readily as an employer masses hundreds of human workers in his factories. The huge armies of the Allies in the World War would seem simple to maneuver compared to the mind-staggering numbers of living, working units which life musters for its ordinary tasks. Yet all work harmoniously, smoothly, side by side, with a minimum of waste and friction.

Corals form some of the most interesting and wonderful illustrations of life's colonies. Let us take them as the first of life's workshops for our examination.

ISLANDS THAT ARE ALIVE

Most of our islands and continents came into being through great changes on the planet. The nearest we come in this twentieth century to observing changes that come in the configuration of the earth is when we see them brought about by earthquakes or volcanic eruptions. These are tremendous events. When a volcano changes the face of the earth, there is a demonstration; fire and smoke belch forth from the mountain top while lava streams and clouds of ashes cover the surrounding territory. That is an example on a small scale of the way many lands and islands were formed in ages past.

But dotted in the Pacific Ocean and jutting out from the mainland of Florida lie coral reefs and islands which were built by living builders. Life works in a way of its own when it undertakes the building business. There is no stir and bustle. There is no hurry. If you were watching from minute to minute you would see little result. But as silently and uneventfully as the flowering of a plant has been the building of thousands of miles of reefs and islands, some parts of which are alive now, other parts of which have been alive, but are now only a memorial of workers of the past.

THE FIRST GLIMPSE OF THESE ISLANDS

"Every one must be struck with astonishment," wrote Charles Darwin, "when he first beholds one of the vast rings of coral-rock, often many leagues in diameter, here and there surmounted by a low verdant island with dazzling white shores, bathed on the outside by the foaming breakers of the ocean, and on the inside surrounding a calm expanse of water, which, from reflection, is generally of a bright but pale green color. The naturalist will feel this astonishment more deeply after having examined the soft and almost gelatinous bodies of these apparently insignificant coral-polyps, and when he knows that the solid reef increases only on the outer edge, which day and night is lashed by breakers of an ocean never at rest."

THE WORKERS

What are these workers which spin out of sea water a substance as hard as stone? Each builder is a soft-bodied polyp, insignificant in appearance, *but alive.* Because it is alive, it can eat and it will work. It takes into itself both sea water, with its mineral elements, and the tiny food organisms floating in the water, which also have some slight mineral content. From these, by the power of its life, it extracts the mineral elements which it can use, and from them builds a wholly new substance, coral. A polyp is no more concerned in the building of its coral framework than a child in the building of its growing skeleton of bones. It is part of its life to build; so it builds. But when its work is done a seeming miracle has been wrought. Out of sea water has come coral; out of a liquid has come, by the working forces of life, a solid.

The polyp's story is not completed when its feat of building is done. Because it is alive, it buds, as the yeast plant buds, and there grow from it other polyps which will build and bud in their turn. One generation dies, but it leaves its coral frames behind, and on these as a foundation the next generation of polyps builds. So, as the years pass and millions upon millions of polyps live, build, and bud into more millions of living, building, budding creatures, coral

ISLANDS THAT ARE ALIVE — CORALS

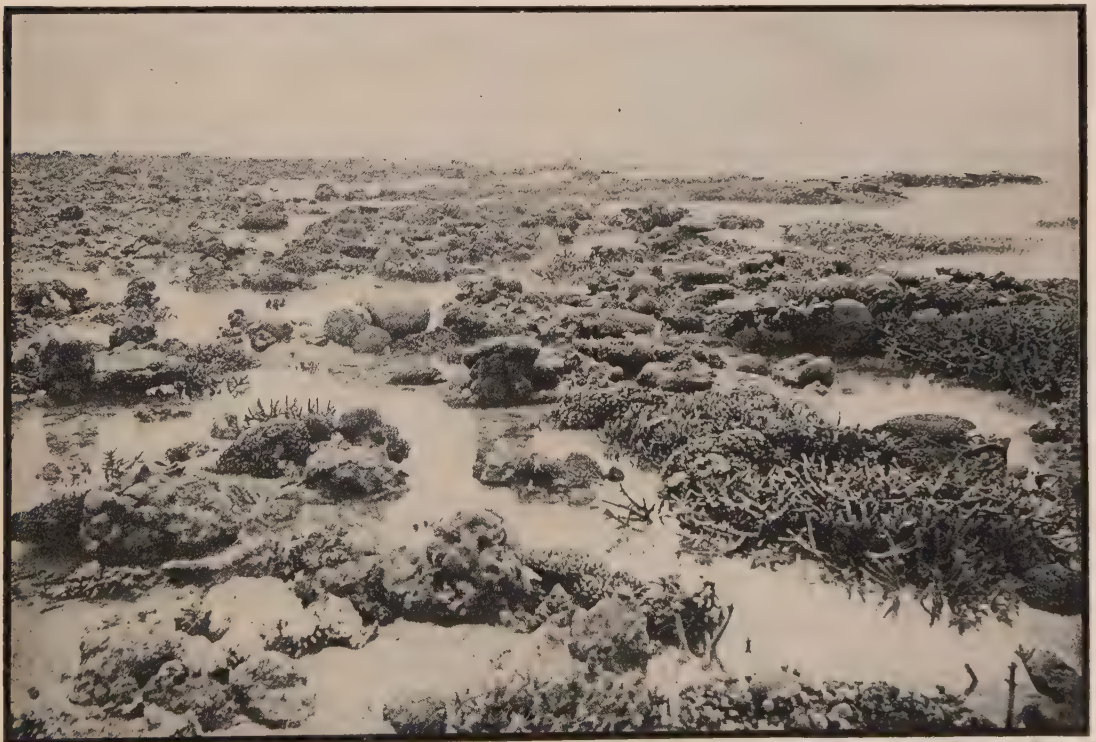
"Millions of millions thus, from age to age,
With simplest skill, and toil unweariable,

Each wrought alone, yet all together wrought,
Unconscious, not unworthy instruments,
By which a hand invisible was rearing
A new creation in the secret deep." — MONTGOMERY.

islands are formed and long coral reefs are run out into the sea.

LIFE IN A WINNING BATTLE

Few if any forces in Nature equal the steady pounding of the ocean as its waves break on a resisting surface. The hardest rock is worn down by its force. Dead coral cannot stand up against it; living corals can. "The strongest and most massive corals," wrote Darwin, "flourish where most exposed. . . . Should the outer and living margin perish, of any one of the many low coral islands, round which a line of great breakers is incessantly foaming, the whole, it is scarcely possible to doubt, would be washed away and destroyed in less than half a century. *But the vital energies of the corals conquer the mechanical power of the waves.*" "The insignificant coral islets stand and are victorious," writes a later observer, expanding this thought of Darwin's; "for here another power, antagonistic to the former, takes part in the contest. The organic [living] forces separate the atoms of carbonate of lime one by one from the foaming breakers, and unite them into symmetrical structure. Let the hurricane tear up its thousand huge fragments, yet what will this tell against the accumulated labors of myriads of architects at work night and day, month after month! Thus do we see the soft and gelatinous body of a polyp, through the agency of vital laws, conquering the great mechanical powers of the waves of an ocean, which neither the art of man nor the inanimate works of Nature could successfully resist."



From photo by W. Saville Kent

ON THE GREAT BARRIER REEF

Off northeastern Australia, twenty or thirty miles from shore, lies this great coral reef twelve hundred and more miles long, containing almost every known form of coral structure.

PLANTS THAT LIVE IN GLASS HOUSES

Of the "grass of the sea," and of houses built by one-celled plants.

THIS is a chapter of wonders. It tells of plants so small as to be invisible to the naked eye, so tiny that one hundred of a kind could be laid on the head of a common pin. It tells of the miniature glass palaces which each one of these plants builds for itself. It tells how the plant which is building this palace has within it a droplet of that magic substance, chlorophyll, by means of which it can harness the energy of a sunbeam and set it to running a food factory. It tells how acres of these plants form the "grass of the sea," the basal food supply of "the world below the brine." In a word, it tells of diatoms which are among the smallest and the most important miracle workers of the world.

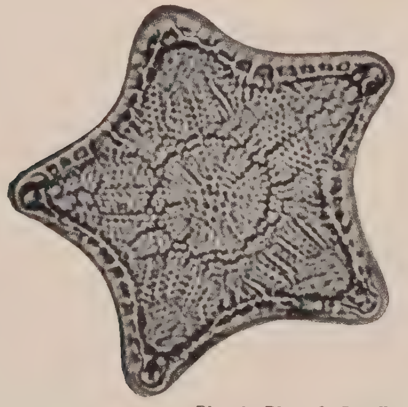


Photo by Philip O. Gravelle
A STAR-SHAPED DIATOM
(Magnified 690 Diameters.)

PALACE AND BUILDER

Diatoms are one-celled plants, abundant all over the world, in ocean waters, in fresh waters, and in damp places. The brown scum on stagnant water may be an accumulation of thousands and millions of diatoms. They are on seaweed, on the stems of fresh-water plants, on wet rocks and walls. If they came together and worked in colonies, as do the corals, to build great branching edifices, we should be more familiar with their accomplishments. But each diatom builds within itself its own independent house or framework.

A diatom has the power of taking from the water silica, which is a mineral compound. In its tissues this silica hardens into an encasing house or box of clear glass. (Quartz, opal, chalcedony, onyx, agate, and other precious stones, are silica compounds; glass and porcelain contain it as a principal constituent.) These glass houses may be round or oblong, thick or thin. The marvel is in their finish. "They are sculptured and carved with such bewildering complexity of design and yet with such perfection of finish." Dotted lines, grooves, pits, and pores help to make the beautiful geometric designs of which specimens, magnified eight hundred or one thousand times, are presented in the photographs (taken through the microscope) on these pages. Only half a dozen species are shown here; there are more than six thousand species, each with its different house. Nearly every symmetrical figure possible to curves and straight lines is included in diatom patterns. "It is a gallery of art, with crescents, triangles, spindles, ellipses, stars (five-pointed to twenty-pointed), and circles." One stands amazed before the hidden beauty and perfection of the world as here revealed.

It is not so surprising that in the higher forms of the plant world where many cells combine to make a whole there should be a great variety of design. Given thousands of cells composing the blossom of a flowering plant, there may naturally be many, many kinds of flowers. But here are single-celled plants, more than six thousand species of them, and each has a different pattern. They can be identified as of the same species when found in widely separated spots. The remains of a diatom which lived long ago can be matched with the house of one of the same family to-day and the two

will show similarity of pattern. "Jewels of the plant world," they have well been called. Each little speck of living, almost formless jelly, plays its part as an artificer, builds its jewel according to its mysterious impulse. Each seems to be a law unto itself. "Yet there is a law within this apparent lawlessness so rigid that the individual species hold their characteristics through thousands of years, and a *Navicula lyra* newly born in the Delaware River is a sister plant of a *Navicula lyra* born millions of years ago in the island of New Zealand."

There is an amazing accuracy about the work of these tiny builders. "The diatom has long been recognized as the most accurate and satisfactory test object for determining the perfection of microscopic lenses," states a scientific report of the Smithsonian Institution at Washington. "All microscopes are to-day tested with one or both of two species of diatoms."

DIATOM DEPOSITS

The plants which build the diatom houses die; but the houses live after them. As in the case of coral reefs, chalk cliffs, and many other earth formations, diatoms have had a not unimportant part in the forming of deposits which remain long after the little plant has died. The vast natural oil resources of California are derived from thick beds of diatoms deposited when this region was beneath the sea in earlier ages. The action of sunlight upon the chlorophyll of diatoms produces oil globules within the plant instead of starch. The great weight and the increasing thickness of sediment brought in by streams have gradually squeezed this oil from the muds into the more porous sandbeds. From these it may be obtained more readily. Fossil diatom earth is also used in the manufacture of polishing powders and as an absorbent in the manufacture of dynamite. Of the fineness of texture of diatom earth we may get an idea by a computation made by Ehrenberg that in a cubic inch of Bohemian diatom earth which he examined there were forty million individual diatom skeletons or remains of houses. Diatoms slip through the meshes of finest silk, when an attempt is made to strain them out of water.

THE GREEN LEAF AGAIN

Thus far our story has been of the wonderful houses these plants build. That would seem a sufficient wonder for the story of a plant of only a single cell. Leave the greater tasks, if there are greater, to larger compound plants, one might say, and let the sole wonder of this plant be its building power and finishing skill. Not so in Nature's economy. Diatoms must bear their part as plants as well as architects and builders. To plants has been given a wonderful talent, on which all the living creation depends. It is the same in the world of water as in the world of air. Each plant that has its bit of chlorophyll, one-celled though it may be, can do what no animal, be it as advanced in the scale

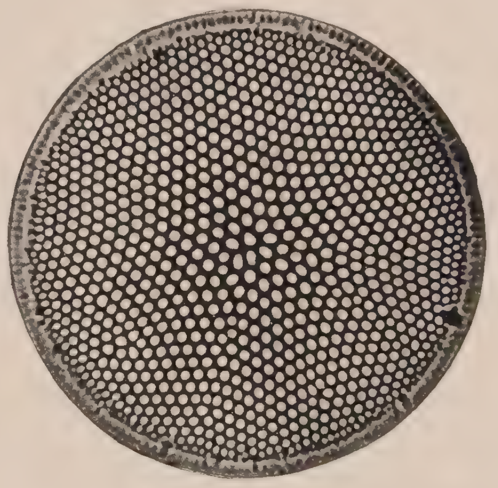


Photo by Philip O. Gravelle

A CIRCULAR DIATOM

(Magnified 1040 Diameters)

of life as the highest fish form or as large as the whale, can ever accomplish. It can take dead matter and turn it into living food material. "Carbon, oxygen, hydrogen, phosphorus, potash, etc., will not juggle themselves into edible compounds," writes Dr. Mason in an article from which we are quoting here. "It is only by the alchemy of the green chlorophyll-bearing plants that these combinations are brought about. The diatom is the smallest of all the green chlorophyll-bearing plants, but despite its insignificant size, these Lilliputian workers are so numerous that the sum total of their activity

is almost beyond calculation. Professor Kofoid has estimated that the average number of diatoms in a cubic meter [a little more than a yard] of water in the Illinois River is 35,558,462. Thriving abundantly in all the waters of the earth, fresh and salt, from the north pole to the south, the countless myriads of these plants are turning the substances held in solution in the waters of the streams and the lakes and the seas into living material and are doing this in that strange alembic where it always takes place, namely, the green chlorophyll grain. By harnessing in some way a sunbeam to its machinery it turns out of the crude material of mineral matter the vital material of plant tissue, and on this plant tissue there feeds directly or indirectly the host of the animals of the sea. . . . It may therefore be said, without stretching the truth, that these plants are the grass of the sea, because they occupy the same important relationship toward the life of the sea that grass does toward the life of the land." In saying this, Dr. Mason does not ignore the other marine plants that contribute to the store of animal food; but "out upon the wide ocean, comprising roughly three-fourths of the surface of the globe, it is the diatom which is the plant par excellence as the supplier of animal food."

Photo by Philip O. Gravelle

GLASS ANCHORS MADE BY TINY SEA CREATURES
(Group Magnified 155 Diameters)

Courtesy of American Museum of Natural History, New York

DEEP-SEA ANGLER, INDIAN OCEAN

LIVING LAMPS

Of cold light as manufactured with marvelous economy in living creatures, of cold light as a possibility for the future.

"WHAT a wonderful sight would be to us a small black fish flitting through the silence and darkness of the deep with its headlights and row of pores gleaming through the darkness like some small ship passing through the night with its port-holes aglow." That is what we should see if we could go down two or three or four miles into the deeps of the ocean.

There exist in many classes of the animal kingdom, "living lamps," that is, creatures that can give out light from themselves. These range from the tiny floating organisms which make the sea shine at night as the oars are dipped into it and drawn out, to the familiar glowworm and firefly of our gardens. But the ones that make the greatest appeal to our imagination are these tiny deep-sea fishes which live so far down in the ocean's depths that they and creatures like them provide all the light that ever shines in those dreary regions. One has a headlight which he can play over the floor of the ocean as an automobile throws its light ahead on the dark street. Others have light-spots on their sides and tails and jaws. All produce this light independently. It is not a reflection, as the shining of a cat's eyes in a darkened room is a reflection from the curtain hung at the back of the cat's eyes. It is light produced by chemical action in the tissues of the creature's body. Glowworms, fireflies, and centipedes give off a green light; the Italian firefly gives off a blue light, and one creature gives off a red light. Sea creatures usually give off either a blue or a light green light.

The question rises instantly in our minds, as we see a firefly flitting about on a summer's night or look at pictures of these strange sea creatures, as to what is the use of this light. Did Nature set out to make a living lamp, as man goes about the manufacture of a lamp? Probably not. Only in the ocean depths can the light given off seem necessary as an illuminant, and there we get figuratively as well as literally into "deep water" when we try to explain its purpose. Every living creature is a chemical laboratory or workshop where there is a constant interplay of chemicals on each other. We saw how color and pattern were a by-product of growth and chemical action. Similarly certain tissues in these fish and insect bodies are so made that chemical action in them gives off light. But when we have said that, have we come to the end of the story? Is all this wonderful display of light an accidental happening with no rhyme or reason for it? With equal force we say "No," but just what are the uses made of this light by the creatures which can create it we do not fully know. It is certainly a means of sex attraction, by which the males and females are brought together, like the songs and the gay feathers of the birds. Many animals move toward a light when they see one. Witness the flocking of insects about a lamp in summer. Probably the light attracts in this way living food organisms to within the reach of luminous fishes. Fishermen are said to cut off the light-bulb from an angler after they

have caught the fish and use it successfully as bait. Lights if they may be suddenly turned on and off at the will of their possessor may serve as protections, to startle enemies and drive them away. They may be used as lanterns, to light the fish's way through dark waters, and they may serve as recognition marks.

COLD LIGHT

These self-illuminating creatures are most interesting to man because in them Nature has turned a trick which man in his workshops has not yet mastered. When man manufactures artificial light he wastes in heat a tremendous proportion of the energy called forth by the operation. Nature's lighting plants are remarkably economical. For a given amount of energy there is a maximum of light with hardly any outgo of heat. "In man's illuminants," says one scientist, "from 96 to 99 per cent of heat is put in for a return of from 1 to 4 per cent of light, but the glowworm gets back in light not 4 per cent but 96 per cent of its inflow of energy." Even if man is somewhat reducing by the latest inventions the waste of heat, he has still a tremendous distance to go before he can match the economy of this chain of Nature's workshops. When man masters this secret, perhaps we shall have luminous walls for our rooms instead of a wiring system and light fixtures. Perhaps our great-grandchildren in the twenty-first century will call in a painter once in so often to paint their walls with a mixture of chemicals which will act on each other to give "cold light." To-day, however, Nature alone has the secret of producing with ease and in abundance this economical kind of light.

A FRENCH SCIENTIST'S PROPHECY

Men are working on the problem, trying to put chemicals together which will act on one another and produce light. A French scientist by the name of Dubois has actually invented a lamp on this principle which will "last a month without going out and without consuming more than two cents' worth of fuel. With this little night lamp one can easily read in the dark or distinguish the objects in a room." He has not been able yet to produce light sufficiently intense to compare with any ordinary commercial lighting. But he makes this prophecy: "Gas with its necessary pipes and its accompanying dangers of fire and of asphyxiation, and electricity with its wires and its non-transportable apparatus, as well as our lamps and candles, are destined to disappear. Since the process by which physiologic light is produced is now perfectly understood and classed among the oxy-luminescences, why may we not hope that the day will come when we shall be able to imitate and even to surpass that made by natural means? We are certainly nearer the solution of the problem than were Galvani and Volta at the time of their immortal discoveries."

We cannot do better than to close our story with Dr. Dubois' beautiful description of Nature's living lights as he has observed them all over the world.

"In every part of the globe, in the air, in the woods and meadows, in the bosom of the waters, there are living signal lights gleaming with strange and shimmering fires, which are incomparably beautiful and suggestive, not only in the eyes of the poet but even more so in those of the savant, for the scientific researches which have been undertaken in the hope of plucking from Nature this marvelous secret of hers are numbered by thousands. Upon the surface of the ocean, sometimes over immense extents, the sea shines with splendor that rivals the starry firmament, while in the depths of its abysses fairy illuminations suddenly blaze forth among the forests of polyps at the passage of fantastic animals, which are themselves wreathed with shining gems, the strange brilliance of whose fires would put to shame the most sumptuous jewels.

"Plants also produce light. In the gloomy galleries through which the miner, ever on his guard against the deadly fire damp, bears his dim and dangerous candle, the myceliums of fungi shine upon old worm-eaten beams with a calm, pale, harmless moonlight gleam. It is these vegetative organs of fungi, also, which in the forests produce the phosphorescence of dead wood and leaves and old stumps. . . . In Brazil and in Australia the emerald green light of other species is so bright that one can easily read a newspaper or see the time on a watch dial by means of it."

HOW FISHES OF THE DEEP SEA LIGHT THEIR WAY

In these tiny fishes (shown almost life-size here), and in glowworms, fireflies, and other creatures which give off light from their bodies, Nature has perfected a system of producing light by chemical action without the enormous waste of heat which is involved in man's lighting systems. Scientists are working on the problem, but they have not yet mastered Nature's secret of economical cold light.

A TREE AS A PUMPING STATION

The force of life, as shown in the tree's hidden fountain of sap.

THE whole life system of a tree might be well compared to a system of water works. Water is the most important factor in the life of a tree. Enormous quantities of it are handled and distributed in an efficient manner which compels admiration.

THE PUMPS

The root tips are the pumps or valves. Through the hairs of the root tips, each tiny hair lined with living matter, water with minerals dissolved in it is drawn into the plant system.

Here we come to an interesting and mysterious fact which the wisest botanists cannot explain. In the soil are various elements, some of which the plant needs, some of which would be useless to it. The root hairs somehow know what to choose. "Not least among the many marvels of plant life is the mysterious power vested in the root of selecting from the surrounding fluid the substances it requires and rejecting others," writes a leading botanist. "Thus if you plant a pea and a wheat grain together in the same soil, the former will take care to make the most of whatever of lime and its compounds the water of the soil contains; while the latter, rejecting these, will absorb for itself the silex or flinty matter." Rotation of crops and the feeding in of fertilizer are the means used by the farmer to keep the soil rich in the elements needed for particular crops. A field sown with wheat for a succession of years would give up to the hungry little root hairs its flinty matter, but would still have mineral substances required by other plants. Another crop could be fed, and well fed, while the soil was given a chance to restore its lacking mineral elements.

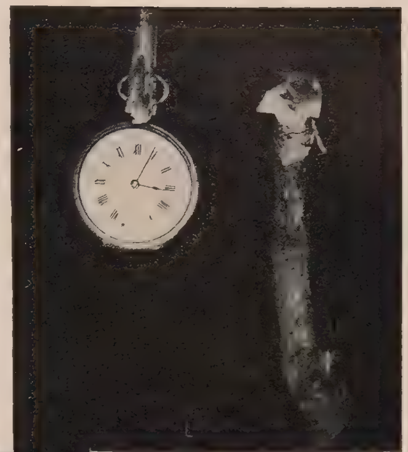
THE PIPING SYSTEM

When the water-absorbing valves have taken in liquid, it is driven along cell tubes through the roots, up the stem or trunk of the tree, and out through the branches to the leaves. There is a long and elaborate conducting system of which the walls must be strong, for there is a tremendous amount of water to be driven up. One of the most fascinating and mysterious facts in Nature is the sudden and forceful uprush of sap through plants and trees in the early spring. Mr. Bastin has shown it for us in an ingenious trio of photographs. In the spring, when the sap would be rising with great vigor, he cut the stem of a grapevine right across, and with as little loss of time as possible tied a piece of bladder (skin) over the surface of the wounded part. At first it hung limp, but within half an hour fluid began to fill it out. The first photograph shows it just before noon, when it was beginning to fill out. Two hours later it had taken on the appearance of a balloon. An hour later the bladder burst under the force of uprushing liquid. Leaf cells are said to sustain an internal pressure of from 150 to 450 pounds to the square inch.

The uprush of sap, if we could see it, must be like the upward rush of a fountain. What forces drive it up? Gravitation must be pulling it down. The pressure of the atmosphere on which many pumps depend would carry it only thirty-two feet into the air, while the giants of the forests may attain a height of four hundred feet. "Recently I had occasion," writes Dr. Ganong, "to calculate the work done in a day in transferring the water from roots to leaves in one of the largest kind of trees, and I found it was just about equal to that which would be done by a man in carrying five hundred large pailfuls of water up a ten-foot flight of stairs within ten hours! This is nearly a pailful a minute for ten hours without cessation."

The amazing fact is that no one knows exactly what does keep this fountain playing. It is known that liquids act on one another and pass mysteriously through skins or membranes which seem to have no openings, and that they act on one another with considerable force. A simple and familiar illustration of this kind of action

comes when dry sugar is sifted over fresh strawberries. As they are left standing the sugar is evidently moistened by the berries and gradually pulls water out of the berries until there is a considerable amount of syrup and the berries are wilted. Something like this action takes place in the root hairs when they absorb water and minerals from the soil. They undoubtedly start the sap upward on its way. More of the same force and other forces enter in which keep the current moving. But when we have said all this, we have not in the least lessened the mystery of this hidden fountain rising dozens and scores of feet into the air in spite of the downward pull of gravity. It is one of the marvels of life's workshops.



AT 3 P.M

Bladder burst under pressure.

At the leaves is applied the power which turns the plant system from a waterworks into a factory. But at the leaves there is also a tremendous discharge of water. The under side of a leaf is covered with tiny openings or doors through which water evaporates into the surrounding air. A leaf may have from one to five hundred of these openings to a square millimeter (one twenty-fifth of an inch). Out of these, water is issuing into the air at such a rate that an average oak tree on a summer day is said to give out from one hundred and fifty to one hundred and eighty gallons of water a day, or twenty-eight thousand gallons in its five active months. A tree acts like a watering pot for the surrounding air. "It is said that the largest steam boiler in use, kept constantly boiling, could not evaporate more water than one large elm would in the same time."

AT 2 P.M.

Bladder full of sap.

Photos by S. Leonard Bastin

BEFORE NOON

Sap flowing upward through a living grapevine stem begins to expand the skin bladder tied over the severed end.

Any one who keeps house plants can prove for himself that water is given off rapidly from the leaves by wrapping tightly in rubber sheeting the pot and soil (which would absorb water) and then putting a glass case over the plant. In a few minutes water will have clouded the inside of the jar. A leaf broken from the parent plant wilts because it gives off its water so quickly. We put cut flowers in water so that they will be able to keep up in some measure the taking in of water as well as the giving out. On a hot, dry day elastic curtains are automatically dropped over the doors of the leaves to hold in the moisture needed by the tree or plant.

If trees served no other purpose, they would be immensely valuable in taking the moisture out of the earth and spraying it into the air. More water is given off into the air by a surface covered with trees and plants than by one covered with standing water.

TREES AS OLD AS HISTORY

A victory of life over death — can trees live forever?

TREES do not die of old age. They are the only living things about us that do not wear out with the years. There is no reason within itself why a tree should ever die. But trees do die, you say; the old apple tree in the orchard and the elms on our village streets are slowly dying before our eyes. Trees die because of accidents which happen to them. Something outside themselves brings disaster to them. A fire burns them, lightning strikes them, insect pests or plant enemies attack them, wind blows them down, cold stops their life activities. But their parts, their living organs, do not wear out as do those of an animal. A tree may become by the way in which it grows (ring by ring) weakened by old age so that it falls more readily a prey to any of these accidents than when it was younger and smaller. That is what has happened to the apple tree and the elms. But old age alone did not bring it to its death. "There is no limit," says John Muir, "to the existence of any tree."

Life has won a great victory here. If we are thinking of life as pushing matter uphill while matter slips back downhill, it has succeeded here in pushing it up and holding it higher and longer than in any other form of life. It has devised a scheme of growth and existence which is almost self-perpetuating. It has nearly succeeded in winding up the clock of a tree so that it will never run down.

THE OLDEST LIVING THINGS

If you find it hard to believe that the right kind of tree under the right conditions might live forever, go out to California and southern Oregon into those groves where a five-hundred-year-old tree is young and a two-thousand-year-old tree is only just arriving at a place of dignity among its mates. "Unafraid of wreck and change, untouched even by 'time's remorseless doom,' they have come down to us through centuries — aye, through millenniums; and now will live on through other centuries, a link to bind the future with the past. . . . There is not a nation on the face of the earth to-day but what was born, mayhap, a thousand years after they reached their maturity. . . . World powers have arisen, run their course, and disappeared — meteors, as it were, in the sky of history — and the big trees still live on." The oldest living things on the continent, these Big Trees deserve an important place in the story of THE WONDER OF LIFE.

WHAT ARE THESE TREES?

The giant trees are all of the genus Sequoia, so named in honor of a great Indian chieftain of the Cherokee tribe. "Once," writes John Muir, "the genus was common, and with many species flourished in the now desolate arctic regions, in the interior of North America, and in Europe, but in long, eventful wanderings from climate to climate only two species have survived the hardships they had to encounter." These are the *Sequoia washingtoniana*, the "Big Tree" of California, and the *Sequoia sempervirens* [always green], which is commonly known as the Redwood. Both are evergreen, of the conifers, the same family as the common pine.

Perhaps you have thought that there were only a few of these Big Trees, a hundred or so, and that they were a curiosity, a freak of Nature. It is easy to exaggerate when one is talking in large figures. So let us take statements from government publications and authorized guidebooks as to the number, size, and age of these trees.

The Big Tree "is scattered in thirty-two groves along the western slopes of the Sierra for a distance of two hundred and sixty miles. . . . There are three Big-Tree groves in the Yosemite National Park, one in the General Grant, and twelve in the Sequoia National Park." The two latter parks have more than a million Big Trees.

A government report gives the height of these trees as from two hundred and seventy-five to three hundred and fifty feet, or in very rare instances calculated to be nearly four hundred feet. This same report gives the diameter as from ten to eighteen feet, or unusually from twenty-five to twenty-seven feet. But the great California naturalist, John Muir, in his fascinating story of his many-year search for Sequoias, tells of an average of twenty feet in diameter, and of many which exceeded twenty-five feet. He was once the guest of a mountaineer who had his home in a fallen Sequoia hollowed out by fire, "a spacious loghouse of one log, carbon-lined, centuries old yet sweet and fresh, weather proof, earthquake proof, likely to outlast the most durable stone castle." The section in the Hall of Forestry of the American Museum, shown in the photograph, is sixteen and a half feet across inside the bark. The tree from which it was cut

Courtesy of American Museum of Natural History, New York

CROSS SECTION OF BIG TREE OF CALIFORNIA

This cross section measures sixteen and a half feet across inside the bark. (For scale, see figure of man standing beside it.) Dates on the wood show how much it grew in each hundred years from 600 A. D. to 1900 A. D.

lived nearly fourteen hundred years, sprouting about five hundred and fifty A. D. and being cut late in the nineteenth century. A section like this is as big as a large room. Yet this is from a tree of only average size.

Interesting as is the size of these Big Trees, by far the greater marvel is the age to which many of them attain. "It is safe to assert," says a government report, "that some of the largest trees are at least four thousand years old, while most of the average large trees now standing, like many that have been cut, are about two thousand to twenty-five hundred years old." Some few trees have undoubtedly attained an age of five thousand years. "Galen Clark, who made a long and careful study of the Big Trees, expressed the opinion that the Grizzly Giant was at least six thousand years old."

HOW A TREE KEEPS A DIARY

A popular style of diary nowadays is "A Line a Day Book." The tree's diary should be named "A Ring a Year Book." Every tree keeps in its trunk a record which even the unskilled can read with reasonable accuracy.

Only a small part of a tree is alive in any given year. There is a living section, starting at the roots, running up inside the bark to the leaves, a layer which is alive. Through it the sap food is flowing. From it all the activities of the tree are fed. Inside that section is a large core of wood, the layers of former years. Immediately on either side of the living layer is a section that is partly alive, partly turning into wood. That is how the wood of the trunk of a tree is built, from the living layers of earlier years; and each layer shows in the tree, if you cut right across the trunk, as a ring. Count the rings from the center to the bark, and you will be able to tell the age of the tree, a ring for each year. Knowing this, you understand why the heart of a tree may be eaten out and the tree live on so long as its living layer is unhurt. You see how a tree might live on forever if in each year it could add its living ring. But let a destructive woodsman girdle the tree, cutting through that living layer, so that the water cannot flow up to the leaves, and the sap cannot flow back through the tree, and the wound is usually beyond repair. The whole tree will die. If you have seen a beautiful birch tree dying because a ring of birch bark was taken off which stopped the flow of life upward and downward through its veins, you will know this lesson in the care of trees as no words could ever teach it to you. A whole tree has been sacrificed for a two- or three-inch strip of bark.

By the hundreds and thousands of rings of the stump of a Big Tree we know the number of years it has lived. "As a hunter keeps a record of the bears he has killed by the notches in his gunstock, so the Big Tree keeps an account of the years it has lived by rings concealed within its trunk. Every year that it lives it grows in girth a tiny bit — in youth faster, in age slower, in fat years more and in lean ones less. But it never fails to add its ring with each passing year."

MATCHING CENTURIES

You can see the rings in our photograph of a cross section, with labels fixed at the different points to show how much it had grown in each century. The tree starts at 550 A. D. The first little white mark shows where the fiftieth ring lies. After that each mark comes at a hundredth ring, that is, at the close of one hundred years, — the first at 600 A. D., the second at 700 A. D., and so on. This is one way to make us picture to our minds how old a tree may be, and how far back fifteen hundred years reaches. Another way is by matching history with the rings of the tree, as our artist has helped us to do. Professor Ellsworth Huntington counted the rings of one tree that was three thousand one hundred and fifty years old. Let us pass by the five-thousand-year trees and the four-thousand-year trees and follow in world history the ages through which this particular tree lived.

HISTORY PICTURES — WHAT THE TREE MIGHT HAVE SEEN

Professor Huntington starts us on our historical pictures. "In the days of the Trojan War and of the exodus of the Hebrews from Egypt, this oldest tree was a sturdy sapling, with stiff prickly foliage like that of a cedar, but far

MATCHING A TREE WITH HISTORY

THREE THOUSAND YEARS AT A GLANCE

This California Big Tree was young in the days of Moses, mature in the years of the golden age of Athens. Five hundred years later it may have been lighted by the Star that led the Wise Men to Bethlehem. More than eighteen hundred years of the Christian era passed before it was seen by white men.

more compressed. It was doubtless a graceful, sharply conical tree, twenty or thirty feet high, with dense, horizontal branches, the lower ones of which swept the ground." To find the story of how Moses led the children of Israel up out of Egypt, you must go back to the second book of your Bible, the Book of the Exodus. To read of the Trojan War, of Helen and the Wooden Horse, you must go to the Iliad of Homer, one of the oldest poems in the world. Yet this tree was living in California in those years.

Jump seven hundred years or more to the date of the Battle of Marathon, 490 B. C., when the huge invading armies of the Persians were being held back by the gallant band of Athenians under Miltiades. Our tree "had lost the hard, sharp lines of youth and was thoroughly mature. The lower branches had disappeared, up to a height of one hundred feet or more." The giant trunk stood out as a bare, reddish column, with the foliage high above the ground.

Five hundred years later it stood, a little larger in girth, a giant Christmas tree on the holy night when the Christ-child was born in Bethlehem. Perhaps it thrilled with the breath of the angels' message as it was wafted around the globe.

Eight hundred years later Charlemagne was crowned on Christmas Day. The tree was now about two thousand years old, the age of the average mature "Big Tree" of the present groves. What will have happened in the world when trees two thousand years old to-day have lived to the age of this tree whose history we are following? They will have watched the year 3000 dawn. Undoubtedly many of the present groves will outlive us by a millennium or more and be honored and studied by men and women of the thirty-first century.

The Crusades began in 1096; Columbus discovered America in 1492; Magellan sailed around the world and Cortez conquered Mexico in the next century. Printing was invented in the middle of the fifteenth century. Galileo was born in 1564 and died in 1642. Harvey discovered the circulation of the blood in 1619. The Pilgrims landed on the shores of the Atlantic in 1620. Two hundred and twenty-one years later, according to the generally accepted view, the first white man gazed upon one of the Big Trees. More than a hundred generations of men had been born, had lived their lives, and had died since this tree was born. Yet only after three thousand years was it viewed by a man of our own race.

THE GREATEST OF LIVING THINGS

Well may John Muir say, "The Big Tree is Nature's forest masterpiece, and, so far as I know, the greatest of living things. It belongs to an ancient stock, as its remains in old rocks show, and has a strange air of other days about it, a thoroughbred look inherited from the long ago — the auld lang syne of trees. . . . Who of all the dwellers of the plains and prairies and fertile home forests of round-headed oak and maple, hickory and elm, ever dreamed that earth could bear such growths, — trees that the familiar pines and firs seem to know nothing about, lonely, silent, serene, with a physiognomy almost godlike; and so old, thousands of them still living had already counted their years by tens of centuries when Columbus set sail from Spain and were in the vigor of youth or middle age when the star led the Chaldean sages to the infant Saviour's cradle! As far as man is concerned they are the same yesterday, to-day, and forever, emblems of permanence." *

"Our forests, like the stars or the changing seasons, are wonders whose lessons and value have become dimmed because of long familiarity. If we saw them but once or twice in a lifetime they would be treasured accordingly. One has but to dwell in a treeless desert for months to have awakened within him such a love for the forests as will last forever." — EDWARD W. BERRY.

* Our National Parks, by John Muir. Houghton Mifflin Company.

A WEATHER RECORD FOR THREE THOUSAND YEARS

Of droughts and floods, of the seven lean years of Joseph, of the famine in the days of Elijah, as recorded by a California tree.

GOVERNMENT weather reports go back only a few score years. The United States Weather Bureau was not established until 1870. Written records of our continent are scanty and often interrupted by long breaks. It was the bright idea of Professor Ellsworth Huntington to read Sequoia stumps for their weather record.

Tree knowledge had established certain facts. The first was the "ring a year" rule; the second, that "the width of these rings shows whether the year was favorable or unfavorable for growth, a thick ring, for example, indicating a moist season, a thin one a dry year." Here were trees that had lived through two or three thousand summers, and had written in their trunks a record of each year. If the climate of California had undergone radical changes in the lapse of centuries, the trees should have recorded the fact. If there had been long periods of drought, that also should be written in their rings. The record of one tree might not be indisputable proof, but if a considerable number of trees all told the same story, there would be a weather and climate record worth having.

It was one thing to have this brilliant idea and reason it out in Professor Huntington's study at Yale University, quite another thing to go out into the Sequoia forests and read the records. Just to give you an idea of what a scientist goes through in the way of hard, painstaking labor before he reaches the conclusions which you and I can read so easily, I am going to quote a paragraph from his story.

"We tramped each day to our chosen stumps, sometimes following old chutes made by the lumbermen to guide the logs down to the valleys, and sometimes struggling through the bushes or wandering among uncut portions of the primeval forests. . . . Our method of work was simple. As soon as we reached a place where Sequoias had been cut we began prospecting for large stumps. . . . The sawn surface exposes the rings of growth so that all one has to do is to measure them, provided the cutting has taken place recently. In the case of older stumps we sometimes were obliged to scrape the surface to get rid of the pitchy sap which had accumulated on it. . . . When all was ready two of us lay down on our stomachs on the top of the stump, or it might be on two stumps standing close together, while the third sought the shade, or the sun, or a shelter from the rain as the weather might dictate. The two who were on the stump were equipped with penknife, ruler, and hand lens. The ruler was placed on the flat surface of the stump with its zero at the edge of the outer ring. Then we counted off the rings in groups of ten, read the ruler and called off the number to the one who sat under shelter with notebook and pencil. Had the lumbermen seen us we should have appeared like crazy creatures as we lay by the hour in the sun and rain calling out 'forty-two,' and being answered by the recorder, 'forty-two'; 'sixty-four,' 'sixty-four'; 'seventy-eight,' 'seventy-eight,' and so on, interminably. It was not inspiring work merely to measure, and it was distinctly uncomfortable to lie on one's stomach for hours after a hearty meal. Often it was hard to see the rings without a lens, and in some cases even the lens scarcely showed them, for the smallest were only two-hundredths of an inch thick, very different from some of the big ones, half an inch thick. Nevertheless, the work was decidedly interesting."

There were many difficulties to be met in the records and in the calculations. In bad seasons one side of a tree would fail to lay on any wood while the outer side had its half ring. There would sometimes be decayed places in the center of the trees. Fire would have burned out a big area of rings on one side, like a deep gash

in the trunk. Again, by the law of their growth a young tree put on a much wider ring each year than an older tree. This had nothing to do with rainfall. In the photograph of a cross section we can see how this works out, the distances in the center being much greater. During the first ten years of its life the average Big Tree adds to its diameter about two inches a year; at the age of two hundred years it adds an inch and four-fifths; at the age of five hundred years, an inch and a fifth; at the age of seventeen hundred, only three-fifths of an inch. With such minute differences as these must all the work be checked if the results were to be an approximately accurate weather and climate record.

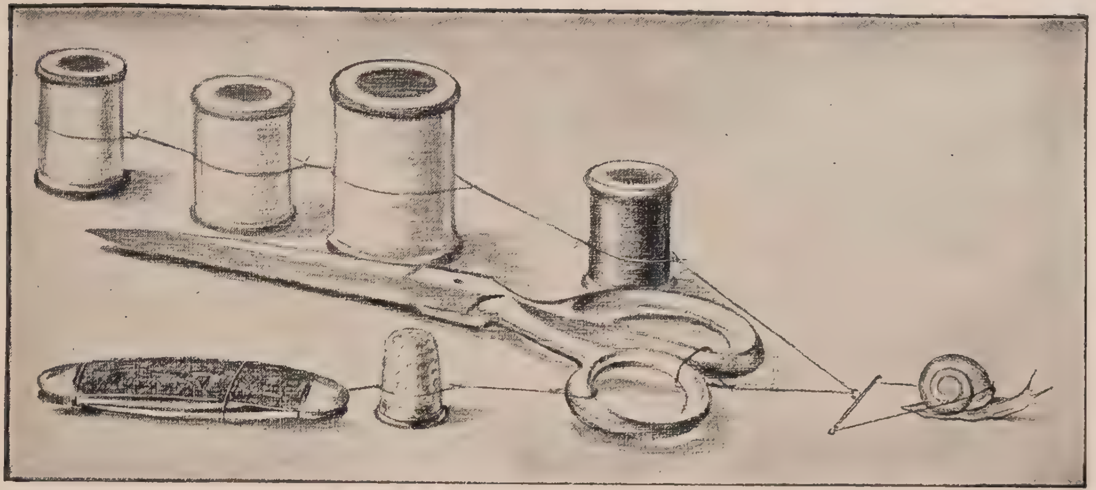
Two hundred tree records were taken, and checked by the most careful calculations. Then a curve was drawn by centuries, like the curve on a monthly weather report, showing rapid growth due to abundant moisture or slow growth due to long-continued drought. The record ran up here and down there, or along for a space with only the ordinary zigzag to show moderate changes, just as a record of the rainfall of the month of August will show a jump up here when there is a heavy rainstorm and a drop below the average when there is a succession of fair, dry days. But once in a while it took an amazing drive upward or drop below the line. With these rises or drops, as the boys would say, "the fun began"; for tree records could be matched with history records to see if they agreed.

The only part of the globe with whose climate records we are at all familiar during the early periods of history is that encircling the Mediterranean Sea and bearing off into Asia. There we have from the national chronicles a fairly good sequence of reports of great climatic changes.

For a hundred years or so, at about 1200 B.C., our tree weather report reads as follows: "Extreme drought lasting over a long period." It would seem that only the remarkable tenacity of this Sequoia enabled it to hold its own during that long succession of dry years.

We turn to the story of Asia in 1200 B. C. It is a period of great famines. Joseph was teaching the Egyptians to save their food in the fat years for the lean years that would come upon them. It is a period of vast migrations. Restless desert peoples swarmed through regions on which they had never before set foot, seeking an abiding place where they could dwell in comfort. And here half around the globe in California a tree confirms the story and shows that it was a world-wide drought. "If America was then inhabited," concludes Professor Huntington, "we can scarcely doubt that similar disasters took place there; for, if the trees are to be trusted, vast areas in dry regions such as Mexico and the southwestern part of the United States, the only places where dense agricultural populations could have dwelt, must have fallen off tremendously in productivity."

In the First Book of the Kings, in the seventeenth and eighteenth chapters, occurs the familiar Bible story of the famine which came upon the land of Palestine in the days of the Prophet Elijah. "Go through the land," said Ahab the king, "unto all the fountains of water, and unto all the brooks; peradventure we may find grass and save the horses and mules alive." That falling off of rain for a short time after an uncommonly fertile period of fifty years is recorded in the tree record in the California forest, as it is also recorded in other regions besides Palestine by historical records. It is an amazing fact, one we can hardly take into our minds and accept. But it stands the rigid test of science. Professor Huntington and others had worked long on the idea that the changes in climate, which they believed to spread over great sections of the earth's surface, were responsible for many of the movements of peoples and the happenings of history. They held that the spread of civilization was closely interlocked with climatic changes. They had the records of history written by men; they had records of dried-up plains, of shrunken lakes, of rocks and rivers, in so far as they could read them. But the inhabited portion of the earth was small in those early days, and there were undoubtedly peoples who came and vanished in the centuries, leaving no written record, like the cliff dwellers of our western regions. For the whole American continent men had left no written records of those years. But a California tree, faithful sentinel keeping its watch through the long ages, wrote its record year by year, to be discovered in this twentieth century and checked with the records of men who dwelt on the other side of the globe in Asia. Truly the ways of life are wonderful, past our finding out!



A SNAIL WITH THE LOAD HE CAN PULL

SPEED LIMITS

Of the slow and the swift as they run life's race.

NATURE will never be fined for reckless and wasteful overspeeding. It has its speed laws and it keeps them. If a creature does not need to go fast to get away from its enemies, it does not waste its energy in rushing madly about for the fun of it. Speed means a faster burning up of the fuel used in the engine. The animal's fuel is food. Food is too hard to get for most creatures to have it wasted in reckless "joy-speeding!"

THE SNAIL AS AN ATHLETE

So the snail with his heavy shell house on his back travels slowly along life's highway, but he gets there. It may be at a snail's pace, but the pace serves. The snail has not chosen to turn his energy to speed. He has a most powerful little engine tucked away within that heavy shell. To carry one's house on one's back for the shortest, slowest journey is no small feat. The snail has muscular energy to drag not only his own shell house but also and in addition a load to the amount of fifty times his own weight. A snail was actually harnessed, as you see him in the picture with a pair of scissors, four spools, a thimble, and a penknife, and he dragged the whole load across the table. An athlete weighing one hundred and sixty pounds would have to be able to drag eight thousand pounds to equal the snail's muscular performance. The next time you have coal put into your bins, picture to yourself a man hauling four tons of coal along the street! It is not for lack of a good engine and a good supply of energy that a snail fails to speed up his pace. He has a speed limit which suffices. Why hurry?

IF PLANTS WERE SPEEDED UP

It is hard for us to believe work is being done unless it is accompanied by a certain amount of speed. Plants are slow-moving; so we find it difficult to believe that they work. "Work is none the less real because it is slow," writes Ganong. "Because plants are placid of mien, and do not hurry and fret and strain, we think they are doing no work. . . . But if plant actions could be magnified immensely in speed they would impress one very differently in this particular. For then the observer would see the tip of every growing plant structure nodding and moving energetically about, so that a meadow, a copse, or a forest would seem all of a vigorous tremble as if straining at some hidden leash: he would see the buds of some flowers open and close with a straining yawn or a sudden snap, and others burst into bloom like a rocket

when it breaks to a spray of mani-colored lights; roots in their efforts to penetrate the earth turning and twisting like angleworms impaled on the fisherman's hook: seedlings in their struggle to break through the ground heaving and straining at their burden of superincumbent soil, like a powerful man at some load which has fallen upon him: seed pods pushing into the earth on a twisting or hard-thrust stalk: tendrils swooping in curves through the air, gripping the first thing they meet, and jerking their plants toward the support."

The season is long. There would be no gain if the plants hurried. So they touch, except in special cases, the lower level of Nature's speed limits, and turn their greater remaining energy to producing and storing food. But when there is reason for speed, Nature's engines produce it, even in animals where we should not expect it.

SPEED FOR SPURTS

It is not always possible to judge of a creature's speed, any more than of its muscular energy, by its looks. A worm crawls over the ground slowly, but let it be endangered by pursuit when it is near or half into its burrow in the earth, and it will dart in with a speed which has been compared to that of a flash of lightning. Many creatures have this ability to move very swiftly for a short space of time. Hunting animals, like the lion and the tiger, leap or dash at their prey with almost incredible speed. The cheetah, an animal half-way between a leopard and a dog, is said to be the greatest sprinter of the animal kingdom. It roams the open country in pursuit of antelopes, and needs its speed to overtake them. "A man who saw a cheetah pursue one of the fleetest of animals, a splendid buck, describes the chase and capture as almost unbelievably swift. The buck had fifty yards' grace before the cheetah saw it, but what happened was almost too fast for the eye to see. The buck went off in great, elastic bounds; the cheetah followed like an arrow. For a second or so there was the bounding form of the buck ahead with an indistinguishable blur behind it, then a cloud of dust, and a buck lying dead with a cheetah over it."

The rhinoceros, the hippopotamus, and the elephant—all big, clumsy creatures—are masters of the art of the sudden charge. They can summon their energies and use them in a tremendous burst of speed. Many of these creatures are good long-distance runners, too. An elephant is said to run fifteen miles an hour. "When he is free and his blood is up, and he is out for mischief, the elephant blazes along a mile in four minutes."

ALWAYS ON THE MOVE

Mitchell, in his fascinating volume on "The Childhood of Animals" from which we have made several quotations, gives a picture of the early life of the young ruminants, the hunted in contrast to the hunting creatures. They are herb eaters, not meat eaters. "In the first place," he says, "they are wanderers. They have to travel long distances in search of water; they must migrate from place to place to find the great bulk of vegetation, of young foliage or herbage that they require as food. Even the large and swift giraffe whose size protects it from all but the most powerful of the carnivores, the strong and savage buffaloes which not infrequently repulse tigers successfully, the agile goats and mountain antelopes which seek safety on the high pinnacles of rocks, and still more the small and defenseless gazelles and brockets, keep alive only by incessant watchfulness and by swift flight from their enemies. They have no permanent home, but from day to day, from hour to hour, almost from minute to minute, they must be ready to rush off. Their habit of rumination is itself an adaptation to this shifting life. They do not chew their food as they crop it, but as quickly as may be fill their huge paunches with a great load of green vegetation, and then fly to a more sheltered place to lie down and chew the cud."

WITH A TIME WATCH

It is difficult to hold a time watch on wild creatures. Different observers in widely separated parts of the globe get different results with individual members of the same animal species. The speed of an ostrich, for instance, is stated as twenty-five miles an hour, fifty miles an hour, sixty miles an hour. One dragon fly was found to skim through the air at a rate of nearly sixty

miles an hour. And so the records might be assembled. Ernest Thompson Seton, in his "Life Histories of Northern Animals," * a careful, accurate, and most interesting set of studies, has made out a table of average speed rates. He says, "It is safe to say that the horse, the ancient standard for speed, still holds its own. There seems to be no good reason for supposing that any creatures on legs — two, three, or four — ever went any distance faster than a blood race horse." Wild animals in general are less swift, according to Mr. Seton, than is commonly supposed, their strong point being the quickness with which they can get up speed. For a race horse the best speed, by his figures, for a mile is at the rate of 34 miles an hour, for a prong-horned antelope 32, for a greyhound 30, for a Texan rabbit 28, for a common fox 26, a northern coyote 24, a foxhound 22, an American gray wolf 20, while a man's best speed is reckoned as at about the rate of 14 miles an hour, of an ordinary runner, about 12 miles, and on allowance for the hundred-yard dash, over 21 miles. These figures are all approximate, but give an idea of the scale of speed rates.

IN THE AIR AND WATER ZONES

Fish attain great speed. A whale has been timed as keeping up with a battleship traveling thirty knots an hour. A mackerel is said to travel at a rate of fifty miles an hour. Fish have also tremendous endurance powers for long journeys. Witness the round-the-world journey of the tunny traveling to the rivers of the Pacific Coast (as told in Volume I, page 246). Our early spring visitor, the robin, has been timed as advancing at an average of thirteen miles a day from Louisiana to southern Minnesota. Its rate increases gradually to thirty-one miles a day in southern Canada, fifty-two miles a day by the time it reaches central Canada, and a maximum of seventy miles a day when it reaches Alaska. It flies from one to two hundred miles in a single flight, but after each long flight rests several days before starting on again. The championship speed for a homing pigeon has been taken as 55 miles an hour for a period of four hours. The great blue heron was timed by a motor cyclist keeping directly below it and found to be going at a rate of 35 miles an hour. A flock of migrating geese was recorded as having a speed of 44.3 miles per hour, a flock of ducks a speed of 47.8 miles per hour.

When speed is desirable, Nature speeds up its engines and adapts its mechanisms to a very high rate. To that conclusion our survey leads us. It pushes the speed limit up, up, up until it equals and exceeds that of most of man's machines, and these extremes of speed are accomplished quietly, easily, and frequently by the living machines which attempt them. But when it is not necessary or desirable there is no pushing of the engines for effect. Nature is economical of fuel and machinery.

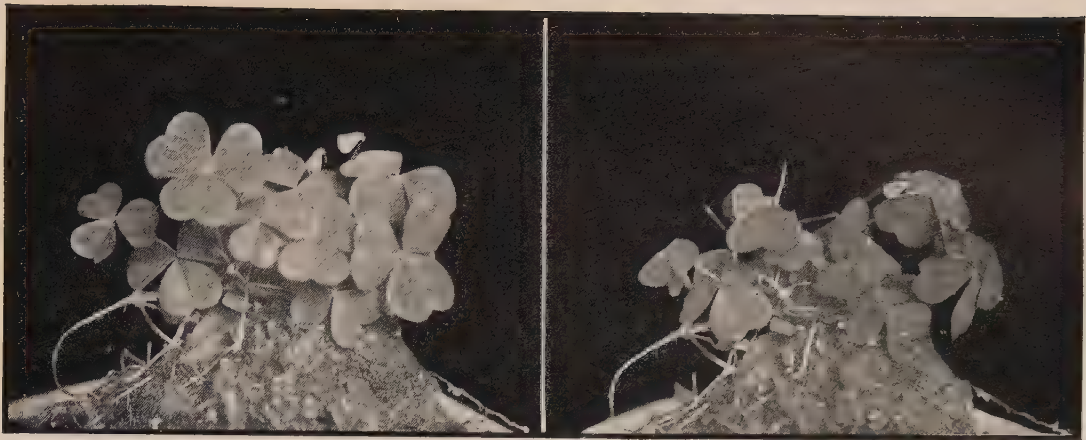
> "The frugal snail, with forecast of repose,
> Carries his house with him where'er he goes,
> Peeps out, — and if there comes a shower of rain,
> Retreats to his small domicile again.
> Touch but a tip of him, a horn, — 't is well, —
> He curls up in his sanctuary shell.
> He's his own landlord, his own tenant; stay
> Long as he will, he dreads no Quarter Day.
> Himself he boards and lodges; both invites
> And feasts himself; sleeps with himself o' nights.
> He spares the upholsterer trouble to procure
> Chattels; himself is his own furniture,
> And his sole riches. Wheresoe'er he roam, —
> Knock when you will, — he's sure to be at home.
>
> CHARLES LAMB.

* Volume I, pages 231 ff. See also our NOTES, page 398.

Photos by S. Leonard Bastin

RIGHT ABOUT FACE

Gaillardias face the sun at 10 A. M., then make a complete right-about to face the afternoon sun at 4 P.M.



Photos by S. Leonard Bastin

WOOD SORREL — BY DAY, AND BY NIGHT

NATURE'S TIME CLOCK

The rhythm of life, in sleep and waking, in summer and winter, in work and rest.

NATURE is a wise taskmaster. Living workshops are run on a careful schedule. Rest periods follow work periods; long vacations follow periods of intense labor. In factories and department stores there is often a time clock installed which has a device to record the hours of labor of employees. Each worker "punches" it when he arrives and again when he leaves; from the record it is possible to know how many hours he is on duty. Nature's time clock is not so easy to read as that. But for a good many creatures and in a variety of workshops it has been read, and we can share the interest of the records. From this study of Nature's rules and regulations we ought to get ideas as to how we should run our own lives, for our bodies are among the most important of the workshops.

The first thing we shall discover is that there is a rhythm in all life, as carefully timed as the rhythm of dance music. Sometimes there is a long beat, again a short; sometimes there is a whole change of movement between different seasons of the year, with a quick "tempo" followed by a very slow one. The bear leads an active life for the greater part of the year; then when winter is approaching, goes into winter quarters for from six weeks to four or five months, giving himself up to a long sleep in which all the functions of life run very low. The sun, sustainer of all life, sets the time for much of this rhythmic movement. The beat of life must be in harmony with the earth's swing about the sun. With night and day go sleep and waking; with spring and autumn go seedtime and harvest; with the rainy season and the dry season go growth and decay. For plants and animals alike, whatever the speed, there is one rule, namely, that rest follows work. Work, rest, work, rest, work, rest, — that is the rule of the shop. To that rule life beats out its rhythm.

DO PLANTS SLEEP?

Sleep is one of the most familiar yet puzzling facts of life. It is the most conspicuous method of taking rest. Among the higher animals there is this obvious knocking off of work at the end of the day, or in the case of night watchers, at the end of the night. Just now we are learning new facts about sleep every year. One of the most interesting questions that is being discussed is whether plants sleep. The photographs heading this page show the change in this member of the clover family from day to night. It would seem as if this plant had drawn down its leaves and composed itself to slumber

after the fashion of the birds and beasts shown on the following pages, which have closed their eyes for the night. But let me tell you a secret which the pictures do not reveal. This plant could be put to sleep at any time by covering it from sunlight. It would not have to be weary — if we can think of a plant as tired — to "go to sleep," or rather to drop its leaves in this way. Shut it in a dark room and the same thing would happen.

So-called sleep movements in the plant world are a mechanical response to the withdrawal of light. There are plants that "wake" by night and "sleep" by day. In this particular plant, for instance, there is a hydraulic device which depends on light to keep it going. At the base of each leaf is a group of cells which swell with liquid under the stimulus of light and hold the leaves out stiffly. When the light is withdrawn, the cells flatten and the leaves droop. That is not sleep. It is a remarkable response to light, akin to the turning of flowers (as shown in our photographs) to follow the sun in its course. These two different kinds of photographs are placed together to show you how there may be a time movement, and even a conspicuous change between day position and night position, or in position for different parts of the day without there being what we should call sleep.

Movements in response to light are very curious and interesting. Sight, in animals, is a response to light. Light waves hitting against the sensitive surface of the retina make changes there which are made known to the brain. A flower cannot "see"; but in swinging around the circle it is making a

Photos by S. Leonard Bastin

CALIFORNIA POPPIES FOLLOWING THE SUN

Before noon; at noon; after noon.

marvelously prompt response of another kind to the light which falls upon it. Such a response seems not unlike the automatic reflex actions of nerves and muscles in the animal world. A plant does not, of course, have a brain and a nervous system by means of which it thinks and controls its acts; but some of them almost "fool" us by these movements into believing that they have. Poets may be nearer the truth than botanists when they credit flowers with some measure of the mind in Nature that makes the whole world kin.

> "And the Poet, faithful and far-seeing,
> Sees, alike in stars and flowers, a part
> Of the self-same, universal being,
> Which is throbbing in his brain and heart.
>
> "In all places, then, and in all seasons,
> Flowers expand their light and soul-like wings,
> Teaching us, by most persuasive reasons,
> How akin they are to human things."
>
> LONGFELLOW.

ARE WE PUT TO SLEEP?

We did not count the drooping of the clover plant as a sign of real sleep because we could make it happen at any instant by putting the plant in the dark. Our reasoning was that there was no weariness, no fatigue. The plant was not tired; it did not need rest. Sleep, for higher animals, seems to be closely tied up with the need of rest. It is a time of repair. Let us see what happens in our own bodies when we go to sleep. The breathing is slower; the temperature of the body falls; the heart action is slower, the blood pressure less; the muscles are relaxed; the sense organs are shut off as much as they can be from receiving messages from without; and consciousness is at its lowest ebb. To sum up, the body has been very active; many of its activities slow down. The mind has been active; it comes as nearly as possible to rest. From what we know of what bodily activity means, we realize that the fuel shoveled in as food has been used at a rapid rate, that the machinery of the cells has been worn and used up, and that waste products (like the ashes from a fire) have been piling up. With the machinery going more slowly, the parts can be repaired and rebuilt, the waste products can be disposed of, and reserve fuel can be stored up. During sleep the body is put in for cleaning, for repairs, and for distribution of supplies. A question is whether certain waste products, the "fatigue poisons," as some of them are called, put us to sleep.

Let me tell you what a scientist did the other day. He took a big dog and had him work, running about and using up his energy, until he was very tired. Then he drew off a very little of the blood which was flowing up into his brain. This blood he injected (as a person is vaccinated) into the veins of a very lively little dog which had just waked up. Within a few minutes the wide-awake dog was as sleepy as the very tired dog. "Its eyelids blinked, its limbs relaxed, its eyes closed, it lost all attention, and it responded but feebly to strong stimulation." Those few drops of fluid had evidently carried something which put the little dog to sleep. There are undoubtedly fatigue poisons which accumulate. It may be

Photos by L. W. Brownell

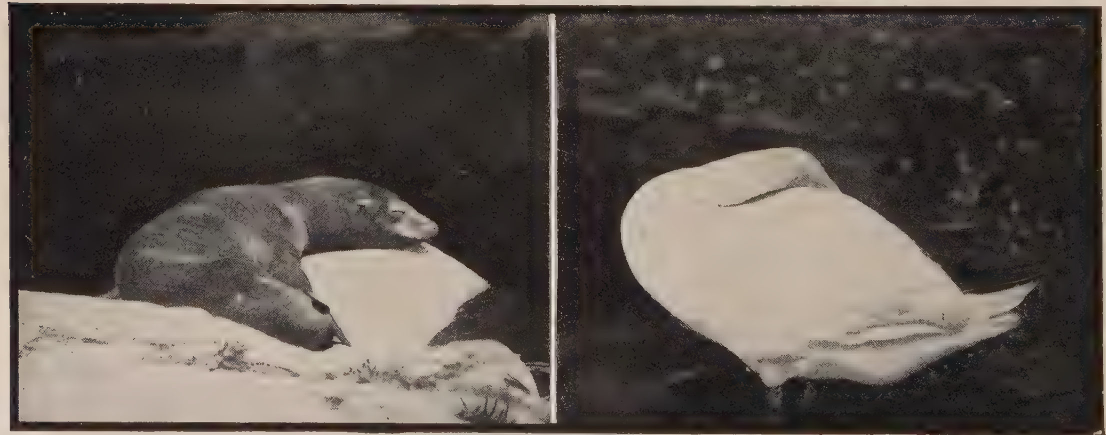
YOUNG PHŒBES ASLEEP BROWN BAT ASLEEP

that when they reach the brain they have the effect of slowing down certain centers of movement. In this sense they help to put the person to sleep.

THE SUCCESS OF THE SLEEP HABIT

Fatigue poisons do not tell the whole story. Indeed, the whole story has not yet been read by the scientists; they have only parts of it. Mind as well as body is concerned with this problem of sleep. There are blood changes and sensation changes, with other bodily symptoms, which may have much to do with inducing sleep. Every one knows that the interested person can put off sleep while he works or plays enthusiastically. Also, a person may become "too tired" to sleep. With all that we do not know, we do know that sleep follows on fatigue, and that refreshment comes in sleep. So, wisely, we do not work on and on until we are overcome by fatigue. Man and the higher animals have developed the sleep instinct or the sleep habit. Regularly as the night comes around they give themselves up to sleep.

The four little birds on the branch have closed their beady eyes, roughed up their feathers, and fixed themselves firmly on a safe, high perch. You may wonder how they keep from falling off when they lose consciousness. A bird's foot has a curious "back-handed" arrangement for this. Instead of having to make an effort to hold on, a bird would have to make an effort to let go. The muscles of the claw are



Photos by L. W. Brownell

SEAL ASLEEP TRUMPETER SWAN ASLEEP

so arranged that they spring back to a position which tightens the hold on the perch, as the letting go of a stretched elastic band tightens it. This is a little thing, but how much difference it makes to the safety and comfort of the weary bird! It is one of those marvelous adjustments of the machinery of life of which there are so many.

The sleep habit, as we have talked of its cultivation by man and the higher animals, implies some consciousness back of it. As we go down the scale of life and have less and less signs of "the animal mind," do we find the creatures still going to sleep? Do fishes sleep? or insects? These are puzzling questions on which there have been many guesses. Sleep seems to act in the animal workshop as a period for repair. Nature keeps a strict balance sheet, with income and outgo. When the columns do not add up evenly, sleep comes in and allows time and the proper conditions for the body to right itself. Undoubtedly the balance is kept in the lower creatures. There may be one-celled or few-celled creatures where income balances outgo so steadily that there is no need of any such rhythmic action. Frankly I myself find it hard to be interested in the problem when it drops below the level of creatures that seem to have some mind in them. Before creatures get far up the scale of life, they certainly fall in to some degree with Nature's plan of alternating work and rest. How early they adopt the day-and-night schedule of work it is hard to tell.

"BUILDING THE ARK" FOR WINTER

In the days of Noah the Lord God gave warning that He would send "a flood of waters upon the earth, to destroy all flesh, wherein is the breath of life, from under heaven." And Noah built an ark into which he brought two "of every living thing of all flesh," of birds and of cattle and of every creeping thing of the ground. "Two of every sort shall come unto thee," said the Lord God, "to keep them alive."

Nature faces in the temperate zones of the earth a problem not unlike that of Noah. In the days when life is at its height, in midsummer, Nature has by some inner sense a warning that all this will be changed. Put into the last line of the old hymn the thought of many, many living creatures as well as of man, and you have in its familiar words the summer motto of all Nature:

> "Work, for the night is coming,
> Work through the morning hours;
> Work while the dew is sparkling,
> Work 'mid springing flowers;
> Work when the day grows brighter,
> Work in the glowing sun;
> Work, for the night is coming,
> When man's work is done.
>
> "Work, for the night is coming,
> Work through the sunny noon;
> Fill brightest hours with labor,
> Rest comes sure and soon:
> Give every flying minute
> Something to keep in store:
> Work, for the night is coming,
> When man works no more."

In this spirit Nature works, preparing for the flood of cold which, like the darkness of the night, will pour in upon it.

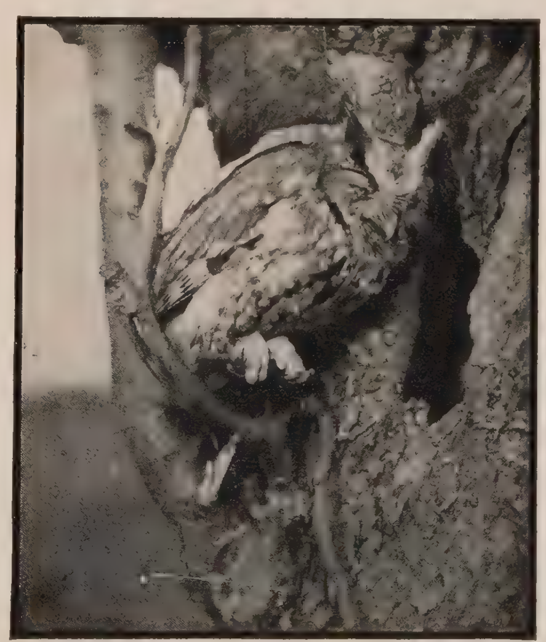


Photo by L. W. Brownell

SCREECH OWL ASLEEP BY NESTING HOLE

Noah built the ark for shelter, and he took into it, at the command of the Lord God, food for himself and for all the living creatures. Nature's care must be to have its creatures find shelter from the intense cold which would stop their life activities and have a sufficient food

Photos by S. Leonard Bastin

THE CHANGE OF THE SEASONS—A RIVER SCENE IN WINTER AND SUMMER

supply laid by to keep them alive until they can safely venture out to get more.

WINTER CLOTHES

Many, many creatures die either at the first approach of winter or before the long stretch of weather is over. A surprising number of animals succeed in finding sufficient food and shelter to keep the fires of life burning and maintain a fairly active existence all through the northern winter. Man succeeds in doing it, but man knows the secret of fire, which the animals have never mastered. When the wintry sun is failing to send sufficient warmth, he has learned by his wit to tap the stores of wood and coal left by the suns of other years and bygone ages. Then, too, man wraps himself in warmer clothing. The animals have in some measure the same scheme for keeping warm. We found in the story of "Suits for All Styles and Seasons" that autumn is a popular time for molting in the animal world. Fur-clothed animals shed the worn summer coats and grow out heavy, close, shaggy winter garments. Birds renew their plumage. We are sometimes apt to think of autumn as a time when all activities of life are slowing down. That is true of late autumn, but in the late summer and early autumn the creatures are very busy packing up for winter, getting their winter suits, finding their winter homes, and storing away their winter food.

ESCAPE BY FLIGHT

Animals as a rule are held to the region where they dwell as firmly as if bound by an invisible cord. Only a few adventurous members of any group have a family habit of long journeys. But for birds the conquest of the air has made possible a means of escape from winter by leaving the cold behind and journeying to warmer climes. The annual migration of these armies of birds from the northern to the southern regions and back again is one of the most marvelous and fascinating events of the year.

It is not difficult to see what starts the birds southward, on their long or short journeyings. The days grow shorter, the food supply lessens, and the cold increases. To escape winter by following the sun on its southern journey is a clever solution. We wonder how it started. The bird could not stay where he was. He would starve and freeze. "Migration was an experiment, an inborn inspiration," writes Thomson, "in the face of untoward conditions. The new line of solution, peculiarly natural to a flying creature, was to evade the difficulties instead of facing them. Thus, instead of hibernating or laying on fat or making a great store of food, birds migrated before the approach of winter. It was a stroke of genius to discover that the prison doors were open." The story of the autumn departure and the spring return is told in a later chapter.

THE NEED FOR REST

In spite of the long journeys which the migrating birds must take, winter is for them a period of comparative rest. Food is fairly easy to get in the winter quarters, and they are free from the labors of rearing a family. For most creatures, whether they travel to the south, go into a winter sleep, or maintain their usual lives as nearly as may be under winter conditions, winter is a period of partial or complete rest. The rest may be a scheme for self-protection, as in the case of the winter sleep of the animal and the closing of all its outer doors by the tree; but it keeps the rhythm of life, which is to work and to rest, to rest and then to work. The outpouring of life in the spring is amazingly swift. Within a week the buds are opening, the plants are springing up, the creatures are moving busily about, and the birds are returning. We must believe that the onrush of spring could not be so rapid were it not for the pause of winter.

The winter is a difficult period to surmount, but Nature by its ingenuity manages it. Life does not have to begin anew each spring. The life of the year before is carried over. As in the days of Noah, saved creatures repopulate the earth. This Nature has learned to do, to carry life over from one season to another, while the seasons move regularly and the clock of time runs neither fast nor slow. And for all living creation the promise holds which the Lord God made to Noah after the flood, that "while the earth remaineth, seedtime and harvest, and cold and heat, and summer and winter, and day and night shall not cease."

As John Burroughs has well put it, "Man sees the end of his efforts because they are limited to his personal wants and aspirations. But Nature's purpose embraces all. Her clock is not wound up for a day, or a month, or a year. It was never wound up, and it will never run down, and it strikes only the hours of eternity."

Photos by Wm. L. and Irene Finley

A CHANGE OF COSTUME—WEASEL IN SUMMER AND WINTER PELLAGE

The summer coat matches the soft colors of the vegetation; the white winter coat harmonizes with a snowy background. But besides this advantage of protective coloration, a white coat is best because of the extreme cold. "The loss of heat is less with white hairs or white feathers than with any other color of dress. It is physiologically the most comfortable dress.

Courtesy of American Museum of Natural History

THIS GOOD OLD WORLD

Life's essentials, and how they are provided on our planet — of water and its work, of air and its service.

IT is a wonderful world to live in, the best of which any of us has any experience. There may be moments when things do not go exactly as we should like to have them; but in general we know that it is a good world in which to live. There are other planets floating about in the solar system, but astronomers have not found a single one on which they would care to take their chances of life. Each has something wrong about it as a dwelling place for living things. Mars has too little water and too thin an atmosphere; Neptune has only one nine-hundredth of the sunlight we enjoy; the moon is a dead world without air or water; Mercury is far too hot for comfort. The thousands and millions of plants and animals that are able to live on the earth are the best proofs that our planet has the right conditions for life. It will be interesting to see what some of those conditions are, and also what the raw materials are which life finds lying conveniently at hand with which to build its products.

RAW MATERIALS

Of the eighty-odd elements which make up the world, life picks about a dozen and a half for its use. Four of these it must have for every product it turns out. The others it uses in greater or lesser quantities, sprinkling a little in here or dropping a few drops in there, as a cook seasons a dish for the table. These four are oxygen, hydrogen, carbon, and nitrogen. Air has three of them, nitrogen making up nearly four-fifths of the atmosphere, oxygen about one-fifth, and the carbon dioxide which contains carbon, about three parts in ten thousand. Water is made up of two, hydrogen and oxygen. It is easy to realize that air is made of gases; but it is harder to think that water, the liquid with which we are so familiar, is made up of two elements each of which when uncombined is found at ordinary temperatures as a gas.

Ellwood Hendrick has remarked that while "the heathen in his blindness bows down to wood and stone," if he had studied chemistry he surely would have worshiped oxygen. Oxygen gives us life; without it we cannot live for many minutes, as we know when we consider how quickly a person dies by drowning. The lungs must have oxygen; if that supply is shut off, life cannot hold its own. Besides making up a fifth of the air, oxygen makes up one-half of the earth's crust and two-thirds of all animal tissue. It is this use of it by life in

animals in which we are particularly interested. We know it best in water.

SPEAKING OF WATER

Water stands out as the most familiar and most important thing in the world. There are so many stories that begin and end with water that it is hard to select.

First, before life takes water unto itself, water performs a great many services that make life possible. A whole chapter could be written on the circulation of water. If water did not move, the story of the earth would be entirely changed. We know water as an engineer carving out the surface of the earth. "Every drop of water," says Burroughs, "finds its way to the sea. It seems as if an engineer had planned and shaped the face of the landscape and the continents with this end in view. But the engineer was water itself. Water flows downhill, and that settles it." Water is always moving *to* the sea; it is always moving *in* the sea. Water flows from the cold depths at the poles to the warm regions of the tropics. Water rises from the ocean as water vapor, circulates in winds and clouds, comes to the earth in moisture and rain, runs in streams to the ocean, and so the endless circle goes round and round.

Because water moves, plants can stay still. Let us see how this works. Plants need light, carbon dioxide, water, and certain minerals. The light comes "with the swing of the sun through the heavens, the carbon dioxide with every breeze that stirs the still air, the water in the form of the mists and the rain, and the minerals in solution in the water which soaks and drains through the soil." Since these are all the supplies which plants require, they have no need to go in search of them, but may stay rooted in the ground, awaiting their arrival.

Water, moving, keeps the temperature of the ocean and the air fairly constant. Life can flourish only within certain rather narrow limits of temperature. Even an increase of a few degrees of heat, or a dropping of temperature below a certain point, makes serious changes in living creatures. Processes are speeded up by heat and slowed down by cold as surely in living cells as over the cookstove or in the refrigerator. Water by its power to hold and give out heat and by its system of circulation keeps the ocean an excellent, evenly heated region for its innumerable creatures to live in, and affects the climate of the earth, keeping the winters fairly moderate and the summers not too extreme.

Water, moving, is the most wonderful common carrier that can be imagined. Here is one of its greatest values for life's purposes. It carries supplies to living plants and animals; it carries them all over their bodies; it picks up waste products and carries them off. There is literally no end to the service water renders life in this capacity.

HOW WATER MANAGES ITS BUSINESS AS COMMON CARRIER

When water carries these substances it does not float them along on its surface. It has a wonderful power of taking all sorts of substances into itself, keeping them there without making much change in them during the period in which it is carrying them, and giving them up to life for its processes when they are needed. When a substance can do this with foreign matter, we call it a solvent. As a solvent there is literally nothing to compare with water.

We have said that water is made up of hydrogen and oxygen. When we say that, we are speaking of "pure water," water before it has picked up anything else; but water is so given to taking into itself all sorts of other things that it is very rarely found without several other things in it. Rain water comes nearest to being pure, but even rain water may have picked up some substances on the way to the ground. You may be sure that when it has been in the ground a very short time, it will have acquired a good deal besides hydrogen and oxygen. It will have picked up the minerals in the soil and dissolved them so that the roots of plants can drink them in with the water. How else could a plant take in sulphur and phosphorus and iron and magnesium and lime, if it could not drink them in with water?

"All elements have been uncovered and set in motion by water. Many of them have been dissolved and carried down to the sea, where they still remain dissolved in enormous quantities. Every mineral has been disintegrated,

ground to dust, and dispersed by the streams and winds. For countless ages, prodigious quantities of all the elements have thus been in motion all over the earth. At present the yearly run-off of the rivers of the globe is believed to be about sixty-five hundred cubic miles, and the dissolved material nearly five billion tons, to say nothing of the sediment." So writes Lawrence J. Henderson, who has made a special study of the usefulness of water on the earth. "All substances," he concludes, "yield . . . to the solvent work of water, and the dissolved parts may all be found in the great final reservoir. It has been proved that nearly every one of the substances which are thus set in motion upon the face of the earth is placed under contribution by life."

HOW LIFE USES WATER

Life makes great use of water as a raw material for its products. There is not a creature alive whose body is not more than half water. Two-thirds of a man's body weight is made up of water. The fish swimming about in the water is itself three-fourths water. As solid a fruit as an apple is four-fifths water; a banana is three-fourths water. Moreover, all living things require water. A plant dies without it. A man may go his forty days without food, but during the fast he must take his daily portion of water. The circulation of blood in the body is a circulation of water which has taken to itself other necessary substances. The digestion of food depends on water as a carrier and solvent. Water carries off the waste products which would otherwise remain in the body and poison it. The evaporation of water from the skin has much to do with keeping the heat of the body down. In plants and animals water is a constant and absolute necessity.

Water, although so strong that it can eventually dissolve and hold in solution any component or ingredient which life needs, is none the less so gentle and mild that it does not attack our bodies save as our bodies require. In the body water might be likened to an automatic housekeeper that goes to the store and brings back to each part what is needed and puts it where it can most conveniently be gotten when desired.

HOW PLANTS STORE WATER

Plants would doubtless choose, if they had any say about it, to have a constant and uniform water supply. Then they could safely give it off from their leaves, as they do in large quantities; they could use it for their food; they could keep an adequate supply in all their tissues, all with no concern whence more water was coming. But plants, as the gardener knows, do not get an absolutely regular water supply. Depending as they do on water, they have several ways of protecting themselves from dryness. One is the ability of the root hairs to draw in water from the soil. Not only do the roots draw from the soil right about them; they seem also to sense the presence of water and will go a-journeying for it, striking off boldly through the soil toward a wet spot some distance away as if they had eyes to see it. So much for underground mechanical aids. Above ground they have, as we have noticed, a waterproof skin for their leaves, with doors in it which shut automatically in a dry time to keep in some of the water which the plant has on hand and would otherwise lose out into the air.

These schemes work fairly well under ordinary conditions, but in regions of extreme dryness, like deserts, more care must be taken if plant life is to survive. In such plants we find the two methods we have mentioned are both practiced more diligently, the roots reaching out farther into the ground and being more absorbent, and the exposed parts of the plants giving out less water. It is a real problem how to shut down this giving out of water without ending the life work of the plant. The plant must have food, which means that it must draw carbon dioxide from the air. To get this there must be openings, and out from those openings water will escape. Some plants cut down the area of their green surface; desert plants are often small, with comparatively few green leaves. Others make a very thick skin, with only a few openings and no chance of escape of water elsewhere. The cactus is an illustration of this device. The cactus practices another device most successfully. It builds large cells in which to store water. Leaves are swollen and rounded out, and stems and roots have good

reservoirs. All these devices serve to remind us how very necessary water is for the plant's life.

ANIMALS AND WATER

Animals of the desert may have, like plants, storage systems. The camel and the dromedary have collections of water cells from which their bodies may draw in long trips across the desert. It is said that the dromedary can store a gallon and a half of water in its inner pouches. Moreover, when these desert animals drink, they drink deep. "It is no simple matter to fill a camel with water," says Dr. Gregory. "His ordinary drink is seven to eight gallons; when thirsty, twenty gallons; but after he has been deprived of water for several days, forty gallons is scarcely enough."

Dr. Edmund Heller, who spent years of exploration in Africa, reported a few animals which seemed singularly independent of the drinking places to which most creatures came regularly. Usually animals will travel miles to these watering holes, where the ground is cut deep by innumerable footprints which bear silent testimony to the universal need for water. A herd of giraffe can go long without water, although they will make use of a near-by drinking place. Herds of hartebeest which drank daily where water was plentiful went into waterless regions and dwelt there, apparently for weeks, with no opportunity to obtain water. Men would have died of the heat and dryness in forty-eight hours. Most beasts would have perished. These observations indicate that the animals managed through vegetation, which is in large proportion water, to get what they absolutely needed. If certain antelopes and giraffes can do that, they have the advantage of being able to escape from the beasts of prey, the lions, which must return frequently

Photos by S. Leonard Bastin

RESURRECTION PLANT — BEFORE AND AFTER THE COMING OF RAIN

to watering holes. Roosevelt says of his own African observation: "When we came across eland, they were drinking every twenty-four hours. But there seems to be no reason to doubt the fact that in certain desert regions eland, like giraffe and oryx, go many months without water. How this is possible for so huge and fat a beast, in a climate of such intolerable dryness and heat, we cannot imagine."

THE IMPORTANT TRIO

We have seen how hydrogen and oxygen unite to form water. The power of the main elements to combine readily with one another is at the basis of all life's work in building up living creatures. If we told you the lists of their known combinations, it would bewilder you to the point of unbelief. But when you look at the matter in another way and remember that you never, or almost never, meet any of these elements alone, but that all the foods you eat and things you handle and wear and see are made up of these main elements with a few more sprinkled in, you understand that they must have a great power of combining in different quantities to form different things. Probably a person who had never cooked or shopped for the kitchen would find it hard to believe that so many dishes are made from flour and sugar and water and a few other ingredients. "Of all the chemical elements, hydrogen, carbon, and oxygen possess the greatest number of compounds and enter into the greatest variety of reactions. The known compounds of carbon, which very often contain all three elements, are numbered by ten thousands, while the possible carbon compounds are almost innumerable." Nitrogen joins with them to make many more combinations, and so the living creation is formed and re-formed. We shall get more out of this side of the subject when we are investigating the foods we eat and need. Now we are interested in the fact that these are the raw materials life finds at hand and uses in its workshops. We can see that they are just what life seems to need. In the book from which we have made quotations, "The Fitness of the Environment," Dr. Henderson not only shows how fit our surroundings are for life, but also speaks of how things might be if life did not find just these combinations at hand and was forced to use others or work under other conditions. Perhaps we shall appreciate our world better if we, for ourselves, indulge in a few inquiries as to how things would be if the world was a bit different.

IF —

A nonsense rhyme of our childhood used to inquire what would happen if the world was apple pie, the trees were made of bread and cheese, the sea of ink, bringing the speculation down to the very definite and pertinent question, If all these things happened "what should we have to drink?" It is interesting to wonder what we should do without so apparently necessary a substance as water. There might be hydrogen and oxygen, but they might unite in different proportions from our familiar H_2O (chemical sign for water, which is made up of two parts of hydrogen and one part of oxygen). Suppose hydrogen and nitrogen set up a partnership. They do in ammonia, which is three parts hydrogen to one part nitrogen. It has been seriously discussed what would happen if ammonia was substituted for water on our planet. It is the best substitute any chemist has found, for it is very like water. It freezes like water, as we know from its use to make artificial ice. It is a good solvent, and it has some of the other excellent properties of water. But it does not require a chemist to tell us that strong-smelling ammonia would be a very poor substitute for our indispensable water.

Suppose, again, that water formed as a solid, as it does in ice, and as a gas, as in water vapor and steam, but never had the stage between of being a liquid. That would never do, for we have seen how all life depends on the free way in which water flows.

Water has a queer property possessed by no other compound of being lighter as a frozen solid than as a liquid, which is to say, that ice floats. Suppose ice did not float, where would life be then? The ice would sink to the bottom of the pond as soon as it froze. More ice would form, and it would sink. The pond would become a solid mass of ice which the amount of heat sent to the earth from the sun would not melt out in all the summer months. All the creatures that are hiding in the mud below the

frost line would perish; there would be no fish or plant life in the water. As it is, the ice freezes over the surface of the pond and keeps the water below at an even temperature, but it does not get low enough to harm the life beneath or within it. If ice did not float, the world would certainly be in a terrible state.

If there was not carbon in the air in the form of a gas, carbon dioxide, life would not long continue. There is carbon in the earth, but how in the world could the plants or the animals get it? They cannot eat coal or coke or diamonds. But a little bit, only three to four parts in ten thousand, combined with oxygen in a gas, is scattered in the air. And out of that little bit the green plants get enough to keep the whole living creation fed up with carbon.

No more "ifs" are needed. We knew it before; we know it better now. It is a wonderful world to live in. We will make the most we can of it, and be thankful every day that we are earth dwellers, not Martians or Neptunites.

IS LIFE POSSIBLE ON OTHER WORLDS THAN OURS?

For our own solar system this question may be answered in the negative, except for the possibility of life on Mars. But our solar system is a very small part of the universe. There are other suns, and they are dotted among stars which are in all stages of development.

For life, as we know it, there must be water and carbon dioxide. Reading the composition of the stars with the spectroscope, the astronomer finds that hydrogen is present upon all stars from the youngest stage on. As the stars evolve, carbon and oxygen come more and more into evidence and abundance. As the temperature of a star falls, in the process of its evolution, the affinity of hydrogen and carbon for oxygen would increase, just as the affinity of these two for oxygen increases in the laboratory as the temperature is reduced. So water and carbon dioxide would form. They must therefore be present upon the cooling crust of the dark stars.

Two requisites for life, water and carbon dioxide, are therefore present. What next? There must be a sun about which this star revolves, as the planets in the solar system revolve about our sun. This sun will supply heat for the planet. It must be neither too near to the planet nor too far from it; else the heat will be excessive or insufficient.

Given this third requisite, a sun furnishing the required amount of heat, and there are possible the following: winds, evaporation of water, rain, streams, springs, soil, — all familiar accompaniments to similar conditions on the earth. Granted winds, a revolving planet, and a consequent difference in temperature and in evaporation between the poles and the equator, and there follows a health-giving ocean instead of a stagnant one.

Our list of requisites is complete. There might conceivably, under such conditions, be life. Since "dark stars" are invisible or only feebly luminous, it is impossible to estimate how many of them there are, or how many may be in just this fortunate relation at any given time with one of the many suns in the universe. Even then the question is not answered whether there *is* life, only whether life like ours might be possible.

IN OTHER WORDS

"Animal life, therefore, presupposes plant life, and plant life the presence of water, the one great neutral solvent, and of water as a liquid. Abundance of water, abundance of vegetation, are necessary if the higher, more developed forms of life are to flourish. But water exists in the liquid form only within comparatively narrow limits of temperature. On the earth water freezes at 32° and boils at 212°, but as the mean temperature of the earth as a whole is about 60° and for the equatorial regions about 80°, there is a wide margin of safety on either side, and over the greater part of the earth's surface, water is normally in the liquid state. In the two frigid zones the mean temperature is 32° or lower. Here, therefore, water is normally found in the solid state as ice or snow. Life exists, indeed, in these two zones, but it exists because for half the year the temperature is above freezing point and because there is continual influx of forms of life from the warmer zones." — MAUNDER.

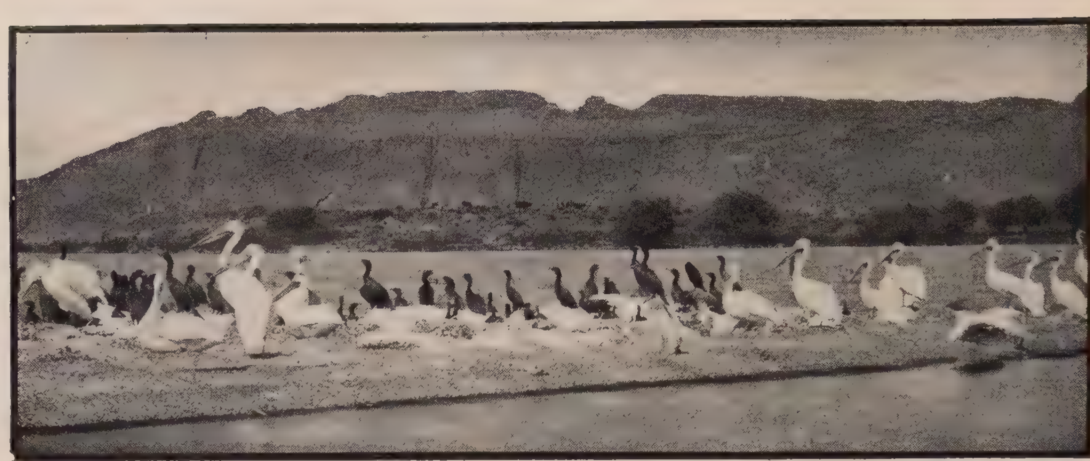


Photo by Wm. L. Finley

EACH AFTER ITS KIND

"And God created great whales, and every living creature that moveth . . . after their kind, and every winged fowl after his kind; . . . And God said, Let the earth bring forth the living creature after his kind, cattle, and creeping thing, and beast of the earth after his kind: and it was so."

JOHN BURROUGHS has given this title, borrowed from the familiar verses of the Creation Story of the Bible, to an essay which every reader of this volume would enjoy reading. Two paragraphs are so beautiful and so in line with our thought of "The Wonder of Life," that I am going to quote them for you, for your present pleasure and in the thought that they may send you to his charming book, "The Summit of The Years,"* which is a modern Nature classic.

"How sharply most forms of life are differentiated! The die that stamps each of them is deeply and clearly cut. . . . Each is a manifestation of the psychic principle in organic nature, but each is an individual expression of it. The chemistry and the physics of their lives are the same, but how different the impressions they severally make upon us! Life is infinitely various in its forms and activities, though living things all be made of one stuff." We have been studying the chemistry and physics of life in its many workshops. Now we come to many little individualities and peculiarities in living creatures, — long necks and short necks, horns and tails and frills. We shall speak of the little ways of life which make each creature interesting, of the way they live together in families and communities, of the way they travel together. We shall consider some of the things they know, and how they know them. Before we begin, let me give you a beautiful picture from Burroughs of the variety of life as shown in a single family.

"Oh! these wild creatures! how clear-cut, how individual, how definite they are! While every individual of a species seems stamped with the same die, the species themselves, even in closely allied groups, are as distinct and various in their lineaments and characteristics as we can well conceive of. Behold the family of rodents, including the squirrels, the hares, the rabbits, the woodchucks, the prairie dogs, the rats and mice, the porcupines, the beavers — what diversity amid the unity, what unlikeness amid the sameness! It makes one marvel anew at the ingenuity and inventiveness of Nature — some living above ground, some below, some depending upon fleetness of foot and keenness of eye for safety, some upon dens and burrows always near at hand; the porcupine and hedgehog upon an armor of barbed quills, the beaver upon his dam and his sharpness of sense. If

* Published by Houghton Mifflin Company.

EACH AFTER ITS KIND

TEN MEMBERS OF THE RODENT FAMILY

All of one family, yet how different in appearance and in manner of life!

they all descended from the same original type form, how that form has branched like a tree in the fields — dividing and dividing and dividing again!"

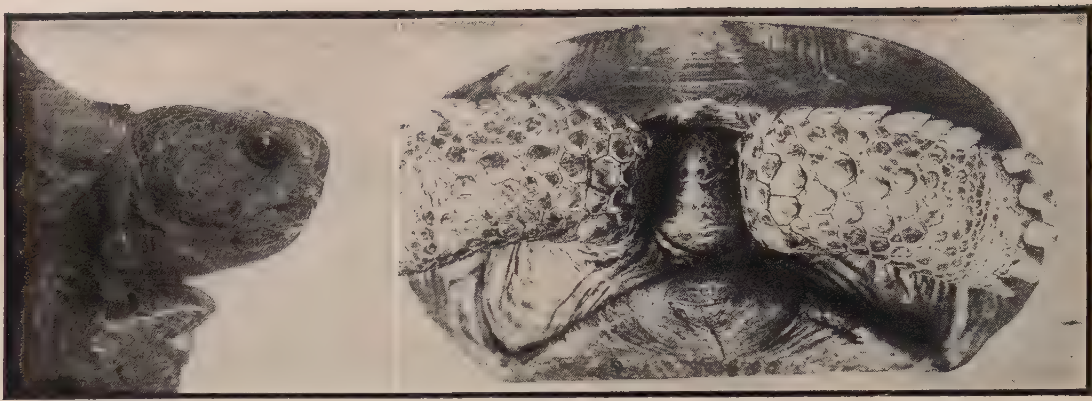
Professor Shimer, who is always looking back of things as they are to see why they are so, would probably tell you that once upon a time there was a type form for rodents, — a first rodent, in other words. Then life tried all kinds of experiments with rodents, and those which worked out best have survived and flourished even unto this day, while those that did not work out well have perished from the face of the earth. He would tell you that those creatures went underground for safety which would not have been able to hold their own on the surface of the ground. Each species stands to his mind as a triumph of life in building and adapting a creature which could hold its own amid all the difficulties and dangers that surrounded it. "Living forms," as Bergson puts it, "are, by their very definition, forms that are able to live. In whatever way the adaptation of the organism to its circumstances is explained, it has necessarily been sufficient, since the species has subsisted. In this sense, each of the successive species . . . was a *success* carried off by life." That is one way to think of living creatures, as successes achieved by life.

Let us be sure that we do not, by any method of approach, belittle the creative dignity of life. In its smallest handiwork and in its largest, life is remote and majestic, unwearying and with a capacity for taking infinite pains. And when we speak of life in its creative work, I like to think of the words which I myself heard Sir Oliver Lodge give as his declaration of faith. "I regard life," he said, "as the rudiment of mind. Life as it ascends the scale blossoms into mentality, mind. It may well blossom into spirit higher than anything that we can imagine."

Photo by E. R. Sanborn, New York Zoological Society

THE OSTRICH, TALLEST OF BIRDS

There is a symmetry between the length of his neck and the length of his legs which is convenient when he wishes to pick up food from the ground.



Photos by R. W. Shufeldt

SIDE VIEW OF TORTOISE HEAD, AND FRONT VIEW WITH HEAD DRAWN IN

SHORT NECKS OR LONG

From turtle to giraffe—necks as examples of life's method of adaptation.

NATURE does not get interested in necks until it gets well up the ladder of life. When it does, what a good time it has trying out all kinds, from the funny little neck of the turtle, by means of which he can tuck his head safely inside a shell, to the amazingly long neck of the giraffe!

Necks belong to life on the earth or in the air. They are neither necessary nor desirable for water dwellers. Backbones begin in fishes, but the jaws and shoulder girdle of a fish are attached to the front end of the backbone, which runs into a skull to hold what brains a fish possesses with no neck between. That is wise, for if a fish were to turn his head from side to side on a movable neck, his self-steering methods would be interfered with. The head could hardly be moved while the fish was swimming without making a change in direction. A fish wants his head to point straight ahead, like the rigid bow of a ship. With a movable head he could not make "those quick arrowlike propulsions upon which most fishes depend for safety and for the successful pursuit of their prey." Whales, porpoises, and sea cows, which live in the water, although they are built on the general plan of land animals, have all the bone structure for movable necks, but in one way or another they have stiffened them up to be as little movable and as nearly rigid as possible. No! necks are evidently no addition to comfort for water existence.

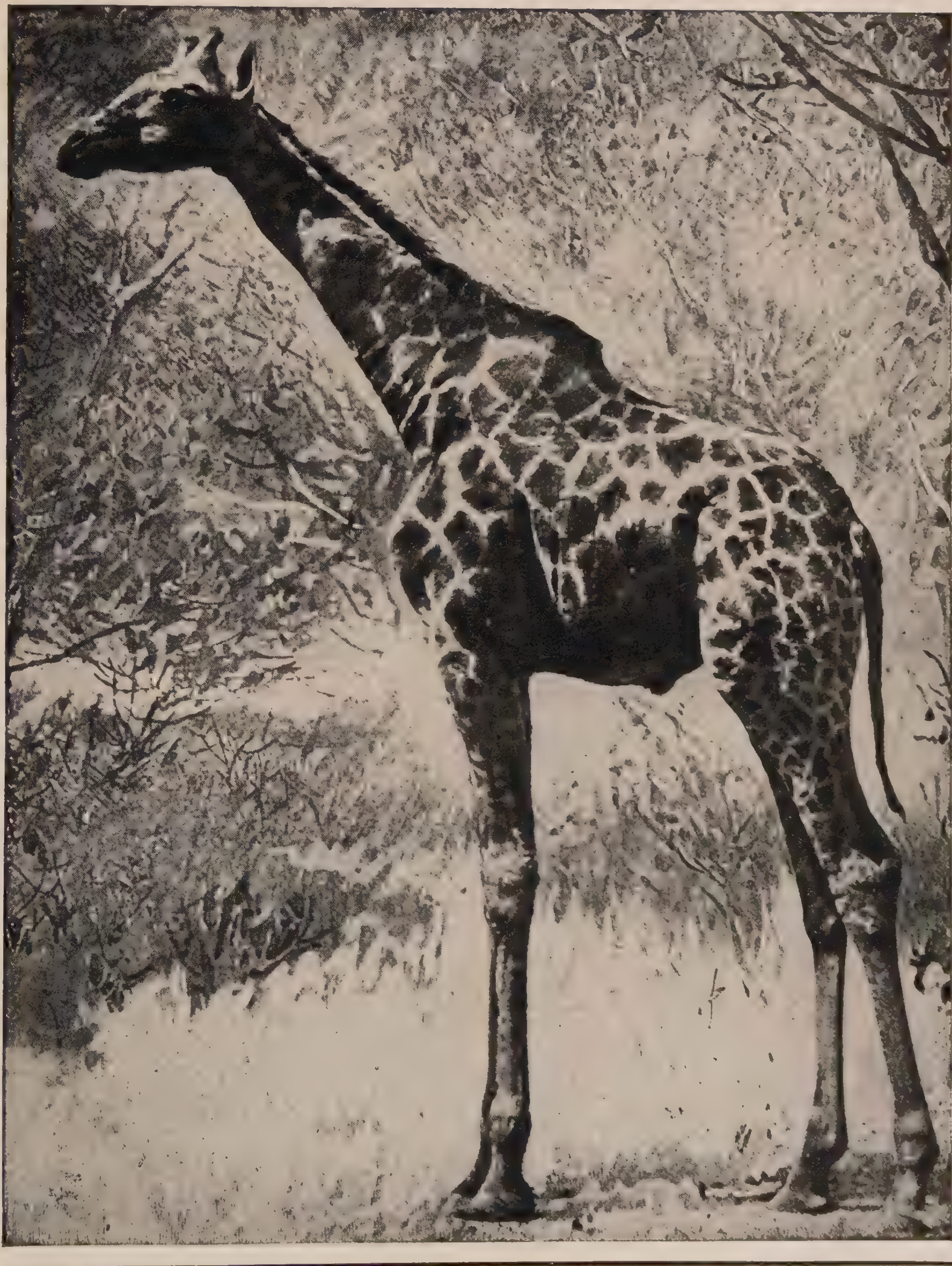
HOW THE TURTLE PULLS IN HIS HEAD

But if a creature is going to live on land or in the air, it wants to be able to look about it. It wants to lift its head above its trunk and turn it this way and that. The turtle does not get a very wide view of the world with his short neck, but it is better than no neck at all. The idea in the turtle family from the first was evidently to play safe. They believed in living in bony armor rather than taking the risks of a flexible but thin skin. They did venture to push out neck and limbs and tail, but they arranged to be able to pull them safely in when danger threatened. Long muscles are fastened back in the shell; he pulls on them as a driver pulls on his reins, and the neck bends and the head is drawn in. It is certainly a most convenient arrangement to get the benefit of a movable head, tail, and limbs, and also to be able to pull them in out of harm's way.

LEFT OVER FROM PREHISTORIC TIMES

The giraffe goes to the opposite extreme. His is the longest neck in the animal kingdom, as he is the tallest of all living creatures. The top of a giraffe's head, when he stands erect, may be sixteen, seventeen, eighteen, and even nineteen feet from the ground. The average room in a modern house is from eight to nine feet high. A giraffe would need a two-story house, with the

TALLEST OF ALL LIVING CREATURES



SOUTHERN GIRAFFE, SURVIVOR FROM PREHISTORIC TIMES

The southern or Cape giraffe has a "creamy or yellowish white ground color, marked by irregular blotches which vary in color, in animals of different ages, from lemon-fawn to orange-tawny, and in older specimens to a very dark chestnut." (*Shufeldt after Dando.*)

second-story floor knocked out, for standing room. Travelers say that it is a beautiful sight to see a large troop of giraffes browsing on the leaves of the tall acacia tree, which is their favorite foliage. To come upon them unexpectedly is like walking into another age of the world's history, for the giraffe is more like the giant animals of prehistoric times, of which only skeletons remain, than like our smaller and more modern animals. "This grotesque animal

New York Zoological Society

SECRETARY BIRD

This strange South African bird feeds largely on reptiles, and is often kept as a pet to rid the premises of them.

stands at the extreme of his family in neck development and height of body," write Roosevelt and Heller in their "Life-Histories of African Game Animals," "and, perversely enough, has been the only member capable of holding his place on the earth. His very grotesqueness and colossal size, no doubt, have been his salvation and have kept him aloof from close competition with the more modern hoofed mammals with which he shares the African continent."

HOW HIS LONG NECK FITS GIRAFFE NEEDS

No one who has seen a giraffe browsing on the leaves of a tree has any question that a giraffe's long legs and long neck are exactly right for the life he leads. If he is going to pick fresh leaves from trees for his diet, he needs his long neck. It is amusing to see him try to pick up a fallen leaf or graze, as would his shorter brethren, on the grass of the field. Even his long neck is not long enough, "so that he has to straddle out his legs by jerks, like a photographer adjusting the height of his camera on its tripod." For good looks as well as for convenience he does well to hold his head high. From a first sight of the creature in his native haunts, we should find a ready answer to the query why the giraffe has so long a neck. Trees being tall, and giraffes wishing to eat leaves from trees, giraffes had to be extraordinarily tall. That goes one step of the way, and a good long step, for it says that this is an example of adaptation, — the giraffe's neck being adapted to his needs.

A SHORT-NECKED MEMBER OF THE FAMILY

The naturalists wish to go a step back of that. They question how he got his long neck. Other animals might have preferred a diet of fresh leaves from trees, but they have to be satisfied with bending their heads to graze on the grass beneath their feet. Within a few years there has been discovered another member of the giraffe family, the okapi, a short-necked member which looks more like a deer or an antelope. This giraffe eats from lower branches of trees or from the ground. It is an interesting story, by the way, how this animal was discovered. Sir Harry Johnston, exploring in Uganda in the Congo region, saw the natives using belts and other articles of skin from an animal which he did not know. They told him this creature lived in the interior and described it to him. After a considerable time he was able to get one of these animals, till then unknown to modern naturalists. It proved to be this short-necked member of the giraffe family. It proved, too, to be an animal which had been noticed in ancient Egyptian carvings, but which the students of ancient history had never been able to identify. Evidently there were many

more okapis in Africa four thousand years ago than there are now; they were so familiar as to appear in many sculptures. They might easily have disappeared from off the face of the earth. They did almost disappear, but in this one region they survived. And we of the twentieth century can see that some members of the giraffe family were content with short necks while others stretched up to the tree tops. If there were at some time a kind of unconscious choice in the giraffe family, how did this physical tendency to length of neck begin?

HOW DID HE GET IT?

One answer that naturalists make is that as the giraffe stretched up and up for leaves, a long neck worked better than a short. So the long-necked members of the family got on better in life than the short-necked, and lived to pass on their long necks to their offspring. This was the first answer that was given to the question. It undoubtedly has some relation to the problem. But constant stretching for countless generations seems a slow and unpromising way to account for such an amazing change of proportion.

A GLAND THAT CONTROLS GROWTH

There have been most interesting discoveries lately about a gland which lies at the base of the skull in animals and man. This gland with its active contents seems to have a great deal to do with growth. Giants, men seven and eight feet tall, have been examined and found to have this gland overdeveloped. It has been noted in studying children that any disturbance in the chemical action within this gland interferes with growth. Dr. Martin says that a man's height is determined by the activity of this little body at the base of the brain, though how it works and how it is notified to stop work when a man has "gotten his growth," no one is yet prepared to say.

Observations on this gland have gone further than that. Individuals in whom this gland was diseased have been watched, and it has been noted that the shape of bony parts of their bodies changed as they would not have changed in subjects of average health and growth. A baby with a normal and healthy pair of hands of ordinary shape had a disease in which the secretions of this gland were abnormally active; its hands actually changed their shape during a long period of observation, and became abnormally broad, with short, stumpy fingers. Another child, with whom the action of the gland was observed to be far below normal, developed a long, slim hand, with tapering fingers, not well-proportioned to the rest of the body. "Thus,"

New York Zoological Society

Another bird on stilts, with so little covering for neck, head, and legs that he looks not unlike the jointed wooden birds of the toyshop.

concludes Osborn, "in a most remarkable manner the internal secretions of a very ancient ductless gland, attached to the brain, . . . affect the proportions of both flesh and bones, as well as the proportions of many other parts of the body."

WHY NOT THIS WAY?

To return to our giraffe problem, — we were asking how a creature could ever have managed to grow such a neck. But if growth is partially

controlled by chemical action in a gland that a giraffe in common with other animals possesses, why not this way? If we went to their laboratories, scientists could show us photographs to illustrate how a dog or a sheep fails to grow if this gland is removed. Why wait, then, even in our thoughts, for a giraffe to stretch his neck through countless generations

Photo by Wm. L. Finley and H. T. Bohlman
WESTERN GREBE

until he got it lengthened out to its present form? Giraffes have these glands, called the "pituitary glands." Why not think that in the wonderful laboratory of growth within a giraffe's body there came at some time in response to some impulse a change in the chemical action in this growth-controlling gland which resulted — whether at once or in a series of such changes in successive generations — in a longer neck? Then, if you will, let the time element come in, and with it natural selection. Doubtless these long-necked giraffes flourished. The leaves of trees too high for their neighbors to reach were theirs to eat and enjoy. Doubtless, like the hero and heroine of the old fairy tales, they lived happily ever after, passing on their long necks to their children and their children's children.

It is no less a marvel and a mystery when we have told this story of possible gland control. For how life rules these inner laboratories and turns out hundreds and thousands of creatures "each after its kind" is beyond our knowledge. All we can hope to do is to get a glimpse into some of the ways in which it may have worked. Certainly there was a time when long necks were the fashion, as you can see by looking at prehistoric animals pictured on page 152 of Volume III. Let us be glad that one long-necked kind of creature lasted over from prehistoric times to our own day.

HOW IT WAS DONE

The giraffe's neck is an actual lengthening out of the bones that make it up; no new bones are introduced. Nature's pattern for making necks for mammals is to take seven bones and fit them together. In all the thousands of kinds of mammals it has made there are only three exceptions to this rule. The neck is an extension of the backbone, and is made in the same way by fitting pieces of bone together. A backbone is a very skillful and delicate piece of mechanism. It must be fairly stiff; that is its reason for being. But it should have some flexibility. If it were all of one piece, it would be as stiff as a ramrod. The same is even more true of a neck. The pieces of bone of which backbones and necks are made are called "vertebræ," from the Latin verb *vertere*, "to turn." Fishes and birds and beasts with jointed backbones are called "vertebrates." (See Volume I, page 242.) For a neck for any mammal from a mouse to a giraffe or a whale Nature requires seven vertebræ. To make the giraffe's long neck it simply lengthens out the pieces of bone.

THE MOST FLEXIBLE NECKS — BIRDS' NECKS

Nature specialized again in necks, this time not in the matter of length but of flexibility and serviceableness, when it made birds' necks. It accomplished these results by using more bones than in most vertebrate necks. Sixteen is a common number of vertebræ for a bird's neck. The swan, needing to pick up food in shallow water, has twenty-three bones in a long and graceful neck. It is hard to believe that the sparrow has twice as many bones in his neck as the huge giraffe; yet such is the case. The separate bones or vertebræ slide back and forth, says Dr. Beebe, like the beads on a string, —

only with this added perfection that they saddle into each other, end on end. These saddles are characteristic of birds and of birds alone; also, every one of the sixteen bones of a bird's neck is different from its fellows. As a result "the neck of a bird has greater freedom of motion than the neck of a snake. A lizard can turn his head only a little way around, and we ourselves can look only across our shoulder, but with a bird it is different. Watch a heron or a flamingo, and see his neck describe figures of eight as he arranges the feathers on his back."

As a turtle's neck fitted well his needs, and a giraffe's neck satisfied his ambition to browse among tree tops, a bird's neck suits his life. With it he can move his back to reach all parts of his plumage and smooth and oil them; he can pick up food from above or below. With so flexible a neck and his well-placed and far-sighted eyes, he is well equipped for the battle of life.

It would hardly seem that a neck could have any part in the expression of emotion. But for several species of birds, as for the frilled lizard, it serves as a base for a conspicuous ruff or frill which may be in its various positions most expressive.

WITH NECK FRILL EXTENDED

From Photos by W. Saville Kent

AUSTRALIAN FRILLED LIZARD

When seen in repose, he looks like any ordinary lizard; but when he moves on the ground he runs very fast and almost perfectly erect on his little hind legs. When angry or excited, he opens his neck frill to its widest. It stands out at right angles to his head, measuring eight or ten inches across.

Photo by R. W. Shufeldt

PREHENSILE TAIL OF BLACK SPIDER MONKEY

TELLING OF TAILS

Of the tail as a fifth hand, an ornament, a balancer, a portable stool, and a food reserve.

TAILS, being something which human beings do not have, are possessions which they are likely to hold in contempt. It is never well to sit in the seat of the scornful. Since tails are the fashion among animals, let us watch different creatures as they go about their daily routine, and see what there is to be said in favor of tails.

"SHADED BY A TAIL"

The squirrel gets his name from his tail, the word "squirrel" coming down from the Greek words *skia*, "shade," and *oura*, "tail." He is literally an animal "shaded by a tail." It is a pretty picture name for this graceful little tree dweller with his long bushy tail and his strong hind legs. These tails, "curving so gracefully over the back, forming so warm a blanket when wrapped about the sleeping owner, and always so expressive, are the badge and pride of the tribe." Such a tail may be credited first as an ornament, though on the practical side it is a most convenient balancer for the squirrel as he darts from limb to limb of his tree home.

In many fur-clad animals the tail seems first and foremost an ornament, a long flexible, sweeping plume, that can stand up straight behind, as in our skunk picture, or hang gracefully down from the body. It is amazing how much emotion a tail can exhibit. It is almost if not quite the most expressive feature of the body in a cat or a dog. How many pictures of joy, shame, satisfaction, and depression in our dog and cat friends pass before our minds as we think of the

wagging tail of the dog, the thumping tail, the tail between the legs, the upright tail of the cat, the swollen tail of the angry or frightened cat, the tail curled around the body and tucked under the chin in slumber! The tail for ornament, and the tail to express emotion — there are two counts in favor of tails, not to mention the suggestion of a most practical benefit of a tail to tree dwellers as a balancer.

A FIFTH HAND

We find in different branches of the monkey family two distinct kinds of tail. Some monkeys have what we might term ordinary tails, that is, tails like those of many other tree dwellers, long or shorter, more or less used as balancers. Others, among which the spider monkey is conspicuous, have the remarkable "prehensile tail," that is, a tail "adapted for grasping or seizing, especially by wrapping round," the name being derived from the Latin verb *prehendere*, " to lay hold." It is this prehensile tail which is shown in the picture at the head of the chapter. Such a tail has been well characterized as a fifth hand. The large thin hairs at the end act in some measure as feelers, "telling of any branch which they may chance to brush." "This prehensile tail is a most curious thing," wrote Waterton in a book describing his "Wanderings in South America." "It is of manifest advantage to the animal either when sitting in repose on the branch of a tree, or when in its journey onward in the gloomy recesses of the wilderness. You may see this [spider] monkey catching hold of the branches with its hands, and at the same moment twisting its tail around one of them as if in want of additional support; and this prehensile tail is sufficiently strong to hold the animal in its place, even when all its four limbs are detached from the tree, so that it can swing to and fro and amuse itself solely through the instrumentality of its prehensile tail."

It is said that a monkey with such a tail will hang from a branch by its tail, drop twenty or thirty feet to a lower branch, catching the latter by its tail, and so drop down from a great height by two or three leaps with no touch of hands or feet to the branches. Again, this tail is used as a hand to bring food to the mouth.

FISHES WITH PREHENSILE TAILS

"The convenience of a prehensile tail for animals which make their airy way swaying from bough to bough in the dense growth of tropic jungles is obvious enough," it has been said, "and the delight with which young and old regard this graceful exercise indulged in by monkeys, either free or captive, is possibly due in part to some deep atavistic consciousness of a time when man, or his immediate progenitors, enjoyed a similar advantage. But what need have the denizens of the deep of such an implement? Obviously none at all so far as the fishes who dwell in really deep waters are concerned, but there are certain curious little fishes, the sea horses and their cousins, the pipefishes, which live in shallow waters near shore and commonly haunt the miniature jungles of eelgrass and seaweed, who find such a power of grasping the surrounding vegetation extremely useful, and who have accordingly developed this prehensile action in a remarkable degree."

The sea horse is unusual among fishes in holding himself erect, head up, tail perpendicular and coiled at the end. When he swims he bends forward and back again, as though bowing, but he is so built that he can hold his tail straight down in the water. His favorite position is to rest bolt upright in the water with his tail coiled about a bit of seaweed. The tail serves him as a finger to grip the weed and anchor him firmly. When he swims, this wonderful tail "coiled up like a watch spring" aids in keeping the body upright. He is not a very good swimmer; his coat of mail holds him so tight that he cannot move by bending a flexible body from side to side as do most fishes. The strong flexible tail makes up in part for the lack of body motion in swimming. In most fishes the tail serves chiefly as propeller; here it steers and balances as well.

TAIL AS A PORTABLE STOOL

Mr. Brearley has well described the supportive tail of the kangaroo as a "portable stool." When we remember the odd appearance of the kangaroo, with a heavy body and short front legs, we can see that a long and strong tail may easily be indispensable. It serves as a balancer in his twenty- to thirty-foot leaps;

it steadies him when he strikes the ground after such a leap; or when he is walking slowly; and it is a most convenient and ever-present support on which to rest the body when he is inactive on the ground.

Gould tells of a little rat kangaroo which uses a prehensile tail to collect and carry grasses with which to line the beds in their underground

TAIL OF LYRE BIRD

burrows. "The appearance of these little animals," says Gould, "when leaping toward their nests with their tails loaded with grasses, is exceedingly amusing."

A TAIL AS A FOOD STOREHOUSE

Little Frog, as you will remember, absorbed his tadpole tail as food during the period when he was turning into a frog, and came out almost tailless. There is a curious sheep found in southwest Asia, in Egypt, and in South Africa which stores food in an abnormally fat tail. It lives in regions where there may be long periods of poor pasturage. This fat-tailed sheep is domesticated now and bred for its fat tail. "It is," says Pycraft, "one of the most remarkable breeds in the world. The tail is of great length and excessive width at the base, and at its maximum may weigh as much as seventy pounds. In such cases the poor sheep is relieved, as much as possible, of its burden by fastening the tail to a board, often mounted on wheels. Here, again, neither freakishness nor ornament has been aimed at, but use, for in times of drought the fat on this tail is slowly absorbed, so that the tail, like that of certain wild animals, is a reserve store of food."

THE LYRE BIRD'S TAIL

There are many more tails which are especially adapted to their owners' needs,— the supporting tail of the beaver, which he uses as a rudder in diving, and with the flat surface of which he can make an astonishing amount of noise by whacking it on the ground; the heavy tail of the alligator, used often as a fighting club; the swishing tail of the horse and other hoofed animals, with which they may brush off insects. There remains one whole class of creatures that possess some of the most beautiful tails there are, namely, the birds. The tail of the flying bird is invaluable for steering, and for checking and controlling movement. But it is of tails for beauty that we wish to speak, — of the two-foot long tail of the pheasant; of the tails of birds of paradise, beautifully shaded with iridescent tints. Of all the tails for ornament one is perhaps the most graceful and unusual, — that of the lyre bird of Australia. This bird seems to be one of the few survivals of an early type. It lives mainly on the ground and runs and jumps more than it flies, though it is well able to fly. The male has the wonderful lyre-shaped tail, sixteen feathers, very long, which when spread take the form of the ancient Greek harp. When he walks or runs this group of feathers is carried horizontally, and makes no more show than any other long tail; but when during the period of courtship he wishes to show off for the fascination of the female, it is held erect in the beautiful curves shown in the sketch.

With this beautiful ornamental tail for courtship our story must end. Surely tails have justified themselves in the animal world.

AN EXHIBIT OF HORNS

HOW NATURE SPECIALIZES IN HORNS AND ANTLERS

At the top of the page, at the left, is the Rocky Mountain sheep; next is the pudu deer of the Chilean Andes, with a tiny pair of spikes; and at the right is our American pronghorn which sheds its horns annually. The bull moose, in the second row at the left, has a wonderful pair of antlers; the rhinoceros, in the center, has two upright horns on the snout; the ibex, a wild goat of upper Egypt, has a long ridged horn. The India cow, at the left, has horns which curve up till they almost form a ring; the black-coated musk ox, in the center, has down-curving horns which turn up at the ends; the American elk, at the right, has beautiful branching antlers. The long straight horns of the African oryx, at the bottom, left, are effective weapons of defense; those of the giraffe are so small as to have lost their usefulness.

HORNS

HOOFS and horns go together. Why, we do not know. Not all hoofed animals have horns, but no animal which does not have hoofs is possessed of horns. Horns are used chiefly as weapons for offense or defense. The color plate of horns might well have been put in the section on "Nature's Weapons," along with tusks. But the bare fact that they are used as weapons hardly skims the surface of the wonder and mystery of horns. Better, it seems, as we look at this strange and beautiful variety of shapes and sizes, to return to our text and think with wonder how they are formed, "each after its kind."

There are facts to tell about horns which you will wish to know. Some are hollow, — those of oxen, cows, sheep, goats, antelopes, and other animals which are called ruminants because they graze and chew their cud; these are usually permanent skin outgrowths which last for a lifetime. Others are solid structures very like bone in composition, and, strange to say, it is the solid horns that are shed. The horns or antlers of the deer family are actually shed once a year. They grow in the mating season, in most cases on males only, and are shed at certain times thereafter. In some species of deer the antlers are mere spikes, while in others they grow to be enormous, of great width and height, with branches that appear at more or less regular points. Again I refer you to our Nature Book, Volume III, with its story of the deer, beginning on page 186, and the photograph of antlers as they grew in a month, on page 190. In that volume the life stories of different animals are told; in this volume, the continued and continuing story of life as it runs through the created world. There you may stop and get acquainted with the characteristics of this animal and that; here you are walking through the avenues of life, holding your thought to one subject and another, now looking at tails, again at toes, and now at horns. Study them on this color page.

First the bighorn or Rocky Mountain sheep, the horns curving up, then down and out, in a graceful trio of bends. Those are formidable weapons, which only the rams possess in such great size, and which they use in their battles with other rams in the mating season. Next to the sheep comes the head of the little pudu deer of the Andes, a creature scarcely larger than a hare, with a tiny pair of spikelike horns. The Rocky Mountain sheep with down-curving horns is matched by the pronghorn, or American "antelope," which is distinguished from near relatives of his family by the fact that like the deer he sheds his horns and grows new ones yearly. The bull moose with beautiful, wide-branching antlers needs no introduction. That strange gray head next him is the rhinoceros, with a long horn and a short one above his nose, on the middle line of the head. Below him, also in gray-black, is the musk ox, with horns curving downward from the head, but turned upward at the ends, making a graceful double curve. The single-horned creature to the right is an ibex, of the goat family, from Egypt. His horn is ridged, long, and very beautiful. Below him is the American elk, with beautiful branched antlers. Next, to the left, the giraffe, with almost disappearing horns. The giraffe looks up on the page at the India cow, whose low-set horns describe almost a complete circle, while below is the oryx, an antelope of Africa, with long, powerful horns running straight back from the head. Truly a varied and wonderful group, fashioned "each after its kind."

To the usual discussion of horns as weapons Dr. Wallace has added an interesting suggestion of horns as recognition marks. In Africa, there are nearly a hundred different kinds of antelopes, in many of which the shape of horn is a chief distinguishing characteristic. These animals keep together in small or large herds. While they were moving among high grass or bushes or were resting, only the horns would be visible at a distance; "and this, in a district inhabited by perhaps a dozen different species of these animals, would be of the greatest importance in guiding a wanderer back to his own herd, and for other purposes."

QUEER PARTNERSHIPS

Between different kinds of creatures, and between animals and plants.

IN the plant and animal worlds, as in the world of human beings, no single individual lives unto himself or dies unto himself. All life is linked up with other life. The flowers need the bees to carry the pollen; the animals need the plants to catch and fix sun energy; birds carry seeds and protect crops by keeping down the possible over-supply of insects; and so it goes on through an endless overlapping cycle. Yet within this great system there are partnerships which stand out as unusual and interesting. It is with some of these queer partnerships that this chapter deals.

CROCODILE AND RHINOCEROS BIRDS

We have spoken of the crocodile birds. "It is a strange sight," writes Verrill, "to see the great reptiles basking in the sunshine, with mouths open wide, while white herons, blackbirds, and other feathered friends of the reptiles walk and hop about, even in the crocodiles' jaws. These chums of the crocodile act as his dentists and pick out the bits of meat and fish which stick to their big friends' teeth."

The rhinoceros has also his bird partners, which feed on the ticks and other insects which swarm in the folds of his thick skin. The rhinoceros bird is also supposed to act as scout and warn the huge rhino of any approaching danger. Here are Roosevelt's comments on the rhinoceros bird, or tick bird, from his "Life-Histories of African Game Animals." "We do not quite understand why the tick birds fail to keep down these ticks [on the rhinoceros]. These tick birds, rather handsome, noisy creatures, are in most places the well-nigh invariable attendants of the rhinos when the latter dwell on the plains or in fairly open bush. They clamber all over their huge hosts, like nuthatches round a tree trunk, and usually go in flocks. So invariably are they attendants upon the big game that if we heard them chattering as we threaded our way among bushes we were always at once on the alert to see a rhino. Sometimes they are wary, and chatter and fly off on seeing the hunter; at other times they pay but little heed; and the rhino may or may not have its suspicions aroused when they fly away."

ANTS AS A TREE'S BODYGUARD

Edward Step gives a vivid account of the ant army which the bull's-horn thorn, an acacia tree of Central America, keeps as a bodyguard. You will see in the picture how the branch is built, with long, stout, curved thorns, set in pairs in such a way that they somewhat resemble a bull's horns, from which they get their name. These thorns will serve to protect the leaves of the tree from the depredations of browsing animals. But they will not protect it from a far more dangerous enemy, the leaf-cutting ants, which climb the trees, cut the leaves, and carry them on their backs to their underground nests. Naturalists tell of just such a procession as is here pictured, streaming down the trunks of trees and along paths through the forest to their great nest heaps, each ant almost hidden under its leaf, the whole procession "looking like a stream on whose surface the leaves are floating."

Against such a destructive enemy the protection afforded by thorns or any similar device would be as nothing. The acacia has come upon a more clever means. It modifies the old adage, "Set a thief to catch a thief," to "Set an ant to catch an ant." There dwell in these forests little ants which possess a sting like that of a bee or a wasp. They live on the ground in dry weather, but when the wet season arrives and the acacia is putting forth new and tender leaves, they swarm up its trunk, for at the base of each pair of leaflets there is a little hollow, into which the plant pours a sweet fluid. "Now along comes the great leaf-cutting ant, intent on carrying home a load of leaves. But the alarm is spread among the much smaller stinging ants, and they immediately do battle

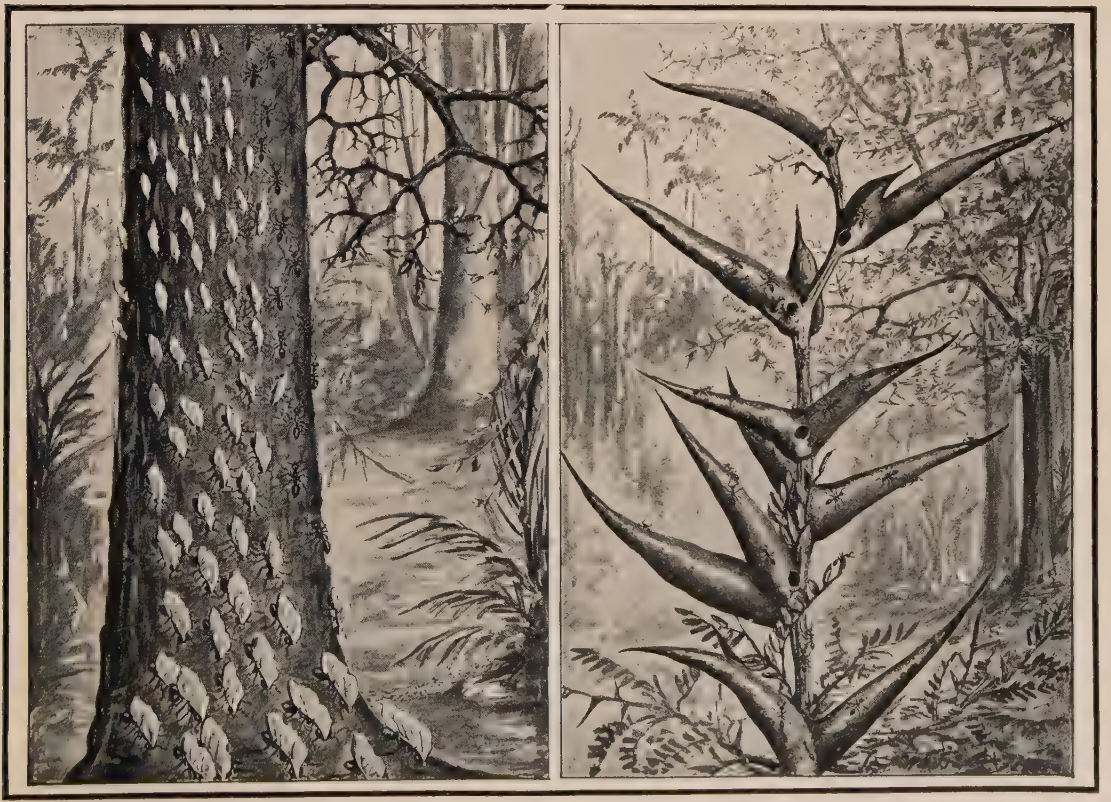
with the Saubas [leaf cutters] and drive them off. There is no enemy the Sauba appears to dread so much as these little stingers. So does the acacia benefit by its outlay of nectar."

The acacia offers more than this temporary hospitality. "It might be only a matter of chance that the stinging ants were in the way when the Saubas called; how much better if the acacia could induce its stinging friends to take up residence on its branches, and so be always on duty, patrolling the ways that lead to them. The acacia puts forth a new set of thorns, and fills them with a substance that will serve as ant food. . . . In these thorns the ants rear their young, and the moment any noisome leaf-fretting insect sets foot upon the plant the ants pour out of these receptacles and make an onslaught upon the intruder."

This is a partnership that has proved most worth while for the acacia. Mr. Belt, who made the most thorough study of this relation, says that he has never seen an acacia that was guarded by the stinging ants effectively attacked by the leaf-cutting ants, while unprotected acacias are swarmed over by hundreds of the little marauders and stripped in an hour of their foliage. That it is worth while for the ant is evident. No bodyguard could expect more than a comfortable home and a constant supply of food.

BIRDS THAT FIND WASPS GOOD NEIGHBORS

In his "Stories of South American Birds," George Cherrie tells of white-billed hangnests, birds which build swinging nests something like those of our orioles, which construct their nest (for this species builds in colonies) in the immediate neighborhood of, or surrounding, the nest of some species of wasp. "Year after year," he writes, " these colonies increase in size as the wasp nest increases in size, and if through



AS ANTS PROTECT THE ACACIA TREE

At the left, an unprotected tree being stripped of its leaves; at the right, a tree protected by a bodyguard of defending ants.

any accident the wasp nest is destroyed or abandoned, within a year or two that locality will be abandoned by the hangnest also. . . . The orioles and hangnests are not the only species of birds that seem to derive protection or company from neighborliness with wasps. Very often I have found nests of the smaller flycatchers near those of the wasps. Apparently there is never any misunderstanding between the respective tenants of the different colonies, but there is little doubt that should a monkey, for instance, attempt to get into a nest of the colony of hangnests, it would be very quickly driven away by the insects."

THE GIANT WATER LILY AND THE JACANA

The giant water lily shown here was first observed early in the nineteenth century on South American rivers. In 1837, the year of Queen Victoria's accession to the throne, it was discovered by a British scientist in British Guiana, and promptly named *Victoria regia*. It has beautiful flowers, in tints ranging from pure white to rose, but its most distinctive feature is its giant leaves. The blossoms are fifteen inches across, the leaves, five or six feet, sometimes even twelve feet, across. They "lie on the water like great circular rafts, with turned-up edges. These leaves themselves are of such choice coloring as to deserve the appellation of flowers. They are of soft shades of light green above; underneath they are in varying tints of red, a red that contrasts beautifully with a light green upper surface, and which forms a marked outer wall for the rim."

But it is with the inhabitants of these marvelous leaves rather than the leaves themselves that we are at this moment concerned. The long-toed bird shown in the picture is the jacana or leaf walker, sometimes called also the lily trotter. The object of these greatly lengthened toes and claws seems to be to enable the birds to stand on these lily platforms, which they haunt for the insects that swarm upon them. They are said to fish from the leaves. At any rate they feed on the insects and small snails which would be harmful to the plant if allowed to multiply undisturbed. So for its hospitality the plant gains the protection which is so desirable, while the graceful leaf walker gains a vantage point and an abundant food supply.

From partnerships like those of which we have given examples, we turn to colonies, communities, and societies of insects and animals as described in the next chapter.

GIANT WATER LILY, WITH THE BIRDS FOR WHICH IT MAKES A HOME

FROM ANT TO ELEPHANT

Social life in colony, community, herd, flock, and pack, — an ant colony as the extreme of communism — higher animals as sociable or gregarious.

THERE are social animals and solitary animals. The ant and the elephant are both social, the one in a close community life, the other in the life of the herd; and between them lie a multitude of creatures, social, partly social, and unsocial. A single family has its solitary wasps and its social wasps. Kipling has given us the classic of solitary life in his story of "The Cat that Walked by Itself," and of social life in "The Jungle Books," where "The Law of the Jungle" is taught, verse by verse and precept upon precept, to the young wolves, who learn that the rule of the pack and the clan stands above all other claims, and finally that

"Now this is the law of the jungle, as old and as true as the sky,
And the wolf that shall keep it may prosper, but the wolf that shall break it must die.

"As the creeper that girdles the tree trunk, the law runneth forward and back,
For the strength of the pack is the wolf, and the strength of the wolf is the pack."

There are three kinds of herd instinct, as we are told,— the aggressive, as shown in the wolf pack which goes forth to hunt; the protective, as shown in the flock of sheep which keeps together for safety; and the socialized, as shown in the ant hill or beehive, where a working community is maintained. Let us begin with this lowest but also very highly perfected type of group life, the ant colony.

ANTS ARE SUCCESSFUL

Social life has worked well for ants. As Solomon remarked many centuries ago, they belong in the list of those things which are "little upon the earth, but they are exceeding wise." They "are to be found everywhere, from the arctic regions to the tropics, from timberline on the loftiest mountains to the shifting sands of the dunes and seashores, and from the dampest forests to the driest deserts." They "outnumber in individuals all other terrestrial animals." Their colonies "are stable, sometimes outlasting a generation of men." There are more than five thousand different species. They have few enemies which really succeed in threatening their existence. Altogether, as a class, they are successful as few animals have been successful, and we cannot doubt that much of this success comes from their instinctive social life.

AN ANT COLONY

Ant colonies are female societies. After her marriage flight the female descends to earth, rubs off her wings, burrows a little chamber which she closes to the outside world, and there waits days, weeks, or even months for the eggs she is laying to mature. During all this time the queen ant takes no nourishment. When the little worker ants have matured, they "break through the soil and thereby make an entrance to the nest and establish a communication with the outside world." They also make galleries, burrowing deeper into the earth. Thus they go forth in search of food, which they bring to the queen mother, who from this time never goes out from the nest but "lives on, sometimes to an age of fifteen years, as a mere egg-laying machine." Worker ants may live from four to seven years. An ant society, then, which may come to have a thousand or ten thousand individuals, is really an "expanded family," depending for its origin on the original queen mother. It shows distinct division of labor. There is the queen and there are females which are to become queens and start new colonies. (In the higher species a colony may have more than one queen.) There are the males, which contribute little or nothing to the colony life but are essential for its continuance. And there are the throngs of workers, females by nature, which do not normally produce eggs but

labor for the good of the community. They get the food, nurse the larvæ of the queen ant, and sometimes carry also the burdens of building and fighting. In some species there is another class, the soldiers, so built that they are especially suited to fighting and to guarding the nests.

Such, in brief, is the simplest ant colony. The fact to be noticed in this type of colony is one typical of all colonies of social insects, namely, that there are actually different kinds of ants adapted for different purposes in the colony life. That is, the physical structure has become in long ages adapted to the social life. A worker could not carry on a separate existence. She is built for social life, serves her part in it, and lives or dies a worker. This is the extreme of communism. The full growth or development of the individual is sacrificed to the good of the whole. Human beings and higher animals do not so merge the individual in the community. Ants, bees, and wasps do this constantly.

THE DRIVER ANT

Driver ants are often compared in their social relations to man in the savage and hunting stages of his early development. They "are the Huns and Tartars of the insect world." They live in the African jungle and have a curious habit of migration from which they get their name, for when they are on the march "every living thing makes room for these ants to pass; if by any chance a mouse or an elephant stands in their road it is forced to speedily move on or remain and be eaten up. The driver ants will not budge an inch from the direction they are bent on traveling; no obstacle will prevent their advance but fire or water. They reign supreme as conquerors amidst the inhabitants of the jungle."

A COLUMN OF ANTS A MILE LONG

The observer from whom we are quoting, Dr. Bowler, goes on to describe their advance thus: "In Africa, just before the rainy season sets in, it is a common occurrence to see long lines of driver ants on the march. They rapidly advance in perfect formation, in lines two or three inches wide, and often extending for nearly a mile, with an organization and military precision that is truly marvelous, as shown by their well-drilled battalions led by their officers. It is interesting to watch the various sections pass at the double, — first a column in close formation, consisting of warrior ants possessing formidable-looking nippers, led by one or more very large ants, twice the size of the others; behind this column follows a mixed mass of smaller ants. These are the carriers, carrying various loads: some bring eggs, others their young, bits of leaves and sticks, grass, berries, dead bodies of insects, and general goods and chattels from their storehouses and towns. All trot along with a determined swaggering air, as if conscious of their irresistible strength by sheer force of numbers. They tear along, tumbling like a cataract over obstacles, and run over one another or not, as the procession winds in and out of the paths in the forest, looking, especially in the moonlight, like a long black snake unfolding itself from the jungle growth." These ants seem to have no permanent home, only temporary nests under the roots of trees, in the crevices of rocks, or in any such shelter. They do great engineering feats of tunneling, form living bridges to carry their number across small streams, and appear to have a system of communication by which they warn of threatened danger and form for attack or defense.

WHEN ANTS BECAME VEGETARIAN

Permanent social life, as Wheeler has pointed out, is possible only for animals that have a fairly abundant food supply within reach. Any animal that has great difficulty in getting food or can find only part of the food supply it craves will tend to become solitary, or, if not actually solitary, will avoid community life where many hungry mouths are congregated. As vegetable food is the only kind that is sure to be abundant, the most successful and well-developed colonies are formed by vegetarians. Beasts of prey and birds of prey tend to be solitary in their habits. The cat and the tiger walk by themselves, the herb-eating sheep and other vegetarians flock together. This is not an absolute rule, but it is true in many cases. Driver ants

must be frequently on the road, for they must seek fresh hunting grounds; some other ants have ceased to be wholly carnivorous and found it both healthy and comfortable to adopt a vegetarian diet. Of these one of the most conspicuous and interesting groups is that of the so-called harvesting ants.

Writers of ancient days made many allusions to the ants which stored seeds in granaries to serve as food in time of scarcity. The advice of Solomon to the human idler is familiar:

> "Go to the ant, thou sluggard; consider her ways and be wise: which having no guide, overseer, or ruler, provideth her meat in the summer, and gathereth her food in the harvest."

Such references, which occur also in many Greek and Latin writers, were thought for a long time to be mythical; but it has been proved beyond any question that there are many different kinds of ants which do "gather food in the harvest." When insect food is lacking, the same strong jaws which would crush insects will crush and grind hard seeds. Here again we find a division of labor. In some groups there are larger workers, or soldiers, with enormous heads and jaws which are actually living "seed-crackers" or "nut-crackers" for the rest of the community, crushing the hard seeds for their weaker brethren. When the time of harvest is over and the seeds are all cracked, it is said that the other ants cut off the heads of these soldiers and throw them away. "A very drastic, but effective, method of getting rid of a superfluous working class."

There is no question that grain is gathered and stored in underground galleries by colonies working in unison. Long files of workers have been observed carrying the seeds to the nests; underground granaries have been opened and as much as half a pint of seeds has been found from as many as eighteen different varieties of plants.

So much for the harvesting ants. Dallas Lore Sharp has told in Volume III, pages 324 to 326, of dairying ants which keep "aphid-cows" and milk them for the honey dew they furnish, and of slave-making ants. It is interesting that slave making does not seem to have worked any better for the slaveholder in ant societies than in human societies. Slave making followed a habit of raiding alien colonies. Among the Amazons, or slave makers, the system goes so far that the ruling class never make their own nests, or care for their young, and seem to be even incapable of getting their own food. "For the essentials of food, lodging, and education they are wholly dependent on the slaves hatched from the worker cocoons that they have pillaged from alien colonies. . . . They sit about in stolid idleness, begging the slaves for food or cleaning themselves and burnishing their ruddy armor." These are the parasites of ant life, living in mixed colonies, where they have a better chance of being served.

Many books have been written on ant life, with incidents and observations that read like fairy tales, showing the coöperation of these little creatures in carrying burdens, in cleaning the nest, in keeping one another tidy, in building elaborate structures, all showing a social instinct by which the individual sinks his own life in that of the colony.

THE BEEHIVE

It is always surprising to find in a sober scientific book a picture that shows imagination. If facts are so stirring that they can move the scientist to fanciful description, they must be vividly colored indeed. In his suggestive book "Instincts of the Herd in Peace and War," on which parts of this study are based, Mr. Trotter indulges in such a picture when he lets his thoughts dwell on the community that fashions and occupies a beehive. Such a community, he says, is very like the body of a complex animal. Our own human body, for instance, is made up of hundreds and thousands of cells, each group doing its special work, all working for the good of the whole. To such a single body, moved by one thought and purpose, he likens the bee community. To see a swarm of bees move is not unlike observing the migration of a single animal, which usually stays in a single spot but under some compelling impulse sets forth for another. The scientist has not overdrawn the picture. A swarm of bees does move as if it were a united whole and does act as if it knew where it was going. It is like an animal in which each unit has retained the power of individual motion. Each bee fits into the group and does its needed part. There

is the familiar division of labor, between the queen bee, devoted to reproduction, the drones or males, and the workers, self-sacrificing females without the reproductive power, which forage for food or act as attendants and nurses for the queen and the young. These workers have no activities of their own. They spend themselves with tremendous energy for the life of the hive, often working themselves to death, it is said, in two or three months by the severity of their labors.

It is fair to add that the very perfection to which the bee attains in this communal life is probably due to the smallness of her mental ability. If she had more mind, she might have more reactions to the outer world. As it is, she throws herself wholly into the life of the hive. Deaf to all other calls, she responds perfectly to the one call she hears. She gives an example of loyalty within narrow limits. As a result, the bee community seems to exert marvelous intelligence. Little-brained though the individual may be, in teamwork the group seems very clever and carries out tasks which no single worker or loosely united group of workers could carry out. The lesson to us who are members of a human society is that these great feats are accomplished only when the single members put the life of the group ahead of every private impulse. As a result, however, the individual in the beehive becomes physically incapable of solitary life.

AMONG THE HIGHER ANIMALS

Among higher animals there is no such sacrifice. The individual does not change physically. It does not give up any of its powers. Groups are for mutual satisfaction, protection, accomplishment, or defense. While ant and bee life are interesting, there is something fatalistic about them. The bees have to stay together and work together if they are to survive. Generations of communistic life have affected their physical make-up so that they are under a compulsion. There is no choice. Gregarious animals of the higher groups seem to have a distinct possibility of choice. Each could eke out a separate or family existence. The fascination of a study of the herd instinct is that while they could probably get along apart, they choose to come together. It may be chiefly for self-interest; but the social instinct does have a freer play.

Ernest Thompson Seton makes a pretty distinction when he classes animals all the way up the scale as gregarious or sociable. Gregarious is a long word that means literally "being in herds." It comes from the Latin word *grex*, "herd," which is found in the more familiar words *congregate* and *congregation*. Gregarious animals tend to live in close proximity with one another and to move in flocks or herds; but they are not necessarily sociable, that is, they do not actively help one another in any way. They

Photo by E. F. Bigelow

WINGS THAT HOOK AND UNHOOK TO SAVE SPACE

If you live alone in your own house, you may spread out your possessions as you please. Live as the honeybee does in a crowded apartment house, and you must do what you can to save space. When he goes indoors he unhooks his wings and slips one over the other. When he goes out again, he can spread them, hooking the "hooks" shown on the edge at the left into the long fold or "eye" of the wing shown at the right.

do not unite their efforts for a common purpose. Bank swallows nest together, but do not help one another. The California murres of Mr. Finley's photograph nest together in crowded rookeries, literally covering the bare rocks. That is to be gregarious. The sociable weaver bird is truly sociable. Frequently from twenty to forty nests hang under the same roof; sometimes there are hundreds, as the society grows from year to year.

Photo by Wm. L. Finley

CALIFORNIA MURRES OFF OREGON COAST NESTING ON SEA ROCK

A SOCIABLE TRIO OF RODENTS — MEADOW MOUSE, CHIPMUNK, AND BEAVER

Rodents are quite inclined to sociability. Drummond voles, more commonly called meadow mice or field mice, "live in crowded colonies, the members of which, to a considerable extent, profit by each others' labors and presence. Their tunnels, runways, midden-heaps, and stores are apparently common property. . . . The village with many streets is apparently a communistic society."

The chipmunks are sociable as well as gregarious. They unite in several efforts. One of the most notable signs of their sociability, as described by Mr. Seton, is the spring chorus. The chipmunk spends his winter snugly hidden away in a deep, dark burrow, far beyond the reach of sun or frost. Almost on the very day when spring arrives in the land, he wakes from his winter sleep and comes forth to greet the sunlight. The first to come into the outer world mounts on a log or root and sounds forth a loud "chuck-chuck-chuck" not unlike a bird call. Other chipmunks, hearing the sound, run from their holes, seek perches, and add their notes to the chorus. So the story of the welcome sunlight is told till all the race that is within hearing comes forth and joins in the salute. Dr. Eastman tells us in his "Indian

Boyhood" how boys will go out in the early morning of a first spring day and one will imitate the chipmunk call. Soon heads will pop out on every side. He himself has seen as many as fifty come to the call.

Beaver communities and beaver engineering feats are so familiar as to need only a passing reference. Together the members of a beaver community will dam up running streams with vast structures of sticks, stones, and roots, mud and sod, till by the work of successive generations dams hundreds of feet long are built. Morgan tells of dams 488 and 551 feet long, respectively. Seton measured one 301 feet long, 15 feet wide at the base, and 4½ feet high in the deepest place, which contained from one to two hundred tons of material and must have required years of labor through successive generations. Beavers also build long canals for transportation of food and other materials, and for easy access to the feeding grounds, and keep these channels three, four, and five hundred feet long, well dredged and in good repair. Occasionally there are lazy beavers, according to Prevost the trapper, who will not do building work or cut down wood for the winter supply. The industrious ones beat them and drive them away. Sometimes six or eight of them will take up a forlorn existence together.

PLANT EATERS

"Most of the big plant eaters of the plains," writes Roosevelt in his account of his African experiences, "as distinguished from the flesh eaters and also from the plant eaters of the forest, seem to crave companionship." The zebra is eminently gregarious, being seen in herds from a dozen to two hundred. Each herd is usually under the leadership of a master stallion, which would round up the mares and drive them whither he wished. He would also trot a few paces toward any strange object, leaving the herd behind and watching intently with ears pricked forward.

Elephants move in herds, wandering over the African continent. Old bulls usually keep by themselves, alone or in small parties; herds exclusively composed of cows and calves are common; but often both sexes are to be found in a herd, and some of the largest tuskers are always accompanied by herds of cows "which seem to take a pride in them and watch over and protect them."

African buffaloes are gregarious, in herds of from a score to a hundred; giraffes are found in small parties, or herds of from twenty to thirty individuals, or singly. Seton tells how buffaloes of the American and Canadian plains have a small local herd and then gather in large bands, hundreds, — in the old days, thousands and millions, — for migration.

A HERD OF CARIBOU

Colonel Buffalo Jones gives a graphic description of a herd of caribou passing in their migration of the year 1892 to the winter ranges. "He stood on a hill in the middle of the passing throng, with a clear view ten miles each way and it was one army of caribou. How much farther they spread, he did not know. Sometimes they were bunched, so that a hundred were on a space one hundred feet square, but often there would be spaces equally large without any. They averaged at least one hundred caribou to the acre; and they passed him at the rate of about three miles an hour. . . . The whole world seemed a moving mass of caribou. He got the impression at last that they were standing still and he was on a rocky hill that was rapidly running through their hosts." It was calculated that the number of caribou in this army must have been twenty-five million. Such animal migrations belong to untenanted territory where man has not yet established himself. With his coming the herds are scattered. Only in island colonies and the remoter regions do we find even birds settling in great numbers. Dr. Chapman describes such bird colonies off Florida, and instances them as examples of pure gregariousness. Here is a limited area into which the birds literally pack themselves for the sake of being together. Apparently it is companionship they wish and nothing else. "When several hundred of one species not only select the same bit of ground for a residence but build their homes side by side, one might infer," writes Chapman, "that they possessed marked sociability of character; but I have hunted in vain for any evidence of friendly or communal relations between thickly

grouped pelican households. . . . They live side by side, they go fishing together, they return together, and this association apparently satisfies an evident desire for companionship."

A FLOCK OF SHEEP

With a flock of sheep it is different. Here protection is afforded. Here a sense of the herd is developed. Here leadership is depended upon.

The first duty of any member of a herd is to sink thought of himself in the thought of the herd. If danger threatens "his first motion must be, not to fly or attack as the case may be, but to notify the herd. This characteristic is beautifully demonstrated in the low growl a dog will give at the approach of a stranger." * This is obviously no part of the dog's program of attack; his first duty from the days of his wolf ancestry is to put the pack on its guard.

It is a slow matter for a sheep to obtain by grazing sufficient food. If he were alone and had to be forever on guard and alert against attack, it is doubtful if he could get enough to eat during the twenty-four hours of the day. But in a flock there are many watchers. The vigilance of each individual against danger approaching in every direction need not be so great. Yet, though less vigilant himself, he gains by the protection of the herd. No single watcher could be as alert. "No one can have watched a herd of sheep for long without being impressed with the delicacy with which a supposed danger is detected, transmitted through the herd, and met with appropriate movement." * There is here an exquisite sensitiveness of the herd and all its members to the signals of its sentries.

Fear, which would paralyze all the necessary activities of the animal, is held in check by his confidence in the herd. The nice distinction is made that "the gregarious herbivora are in fact

Photo by Rollo H. Beck

GROUP OF MARINE IGUANAS, GALAPAGOS ISLAND, ECUADOR

Iguanas are large tropical lizards, sometimes five or six feet long.

* Trotter.

timid but not fearful animals." There is an appearance of calm about a grazing flock of sheep which represents rightly the feeling of the flock. With all his timidity and his quick start at the unfamiliar sound, the sheep is not conspicuously fearful while in the company of his fellows. When fear does take possession of the herd, then there is panic and stampede. The fear held in check so long is the greater when it is felt not only by each member singly but by the herd as a whole. Roosevelt tells how the African natives do not like to have herds of zebra in the neighborhood because they are thrown into unreasoning panic at the hint of the approach of a lion and will stampede blindly, trampling down gardens, going through wire fences, and demolishing everything in their path.

It will be seen that while in the ant or bee community each member was adapted in his *physical* make-up to the group life, in the herd of higher animals the adaptation is *mental* and *emotional*. The sheep is different from what he would be if he were compelled to lead a solitary life. He reacts differently to danger; he responds to any movement of the group; he sinks his own individual fears. He may be exactly the same physically as if he dwelt entirely apart; but the sheep that has grown up in the flock and never been separated from it is a different creature in mind and feeling from what he would be otherwise.

When we come to this point, we are getting nearer to man and his social life. Man is a gregarious animal. He is a social being. He takes comfort in the presence of and closeness of his fellows. He dislikes solitude. He responds to leadership. Man does not stop with responding to the herd instinct. He goes far beyond the animals. In him the herd instinct flowers out into other more ideal responses. But as we study the herd instinct in animals, we can match it up in many ways to the instinctive responses of human beings.

THE AGGRESSIVE TYPE — THE WOLF PACK

The wolf pack is the best illustration of the aggressive and attacking group. To the wolf the herd must be not simply a source of comfort, of suggestion, and of guidance; it must take him as a unit and make him part of an attacking, fighting machine. To it he must give complete obedience.

> "Now these are the laws of the jungle, and many and mighty are they:
> But the head and the hoof of the law and the haunch and the hump is — Obey!"

The strength of the wolf pack is enormous, far more than that of any single attacking individual, because of this singleness of purpose.

To gain this unity, resort is had to certain devices. "The wolf is the father of the war song." Any herd, whether socialized like the bee, protective like the sheep, or aggressive like the wolf, depends on its members being able to recognize and to communicate to a certain extent with one another. Ants and bees have been shown to accomplish this by the sense of smell. Man's high development of the group system in all civilized relations is largely due to his power of speech. The better the system of communication, the larger and more successful the working whole may be. From the village man has progressed to the county, the state, the nation. The cable and the wireless station are enabling him to communicate with the whole world. An animal group, like a wolf pack, is very sensitive to the encouragement given by the sound of one another's voices. The pack "gives tongue" and gains new strength in the process. The war song is a distinct feature of the herd attack.

Naturalists differ as to whether to rank the protective type of herd or the aggressive higher. Seton makes an excellent point for the wolf pack as having the higher element of choice. "Wolves," he says, "are the most sociable of beasts of prey. Not only do they gather in bands, but they arrange to render each other assistance, which is the most important test of sociability. . . . The packs are probably temporary associations of personal acquaintances, for some temporary purpose, or passing reason, such as the food question or mating instinct. As soon as this is settled they scatter. No doubt the same individuals are ready to reunite as soon as a new occasion requires it, and would resent the presence of a total stranger. This I take to be true sociability."

Photo by L. W. Brownell

THE SHOVELER, A DUCK THAT TRAVELS TEN THOUSAND MILES TO WINTER QUARTERS

HIGHWAYS OF THE SKY

Of the marvels of bird migration, of distances covered and routes followed.

ONLY in this twentieth century are human beings beginning to take account of the realms of the air and to count their territorial possessions as extending into a third dimension, skyward. It is the newest thing in a new world for governments to be planning to chart the sky and lay out highways marked by signs to guide aviators along the accepted routes. But the birds have done it since the beginning of time. Their highways were laid out centuries and ages ago, and are traveled by hundreds and thousands of feathered aviators.

We who have been so long earth-bound exclaim over a transcontinental or transoceanic air trip, and well we may, for it is a triumph of mechanical endurance and human skill and daring. But lest we become boastful over our new accomplishments, let us not forget the feathered aviators which make similar and greater journeys as part of their yearly routine. One hundred or more species of our common birds make no difficulty over summering somewhere in North America and wintering in South America. Nineteen species of shore birds breed north of the Arctic Circle and visit South America in the winter. The maps show eight-thousand-mile highways traveled yearly by birds that measure their length in inches and carry the fuel for their engines in the food supplies which they can take in the rare intervals of landing and in the fat of their own little bodies. Not simply one bird here and another bird there accomplishes these feats. If there was ever a period of lonely experimental flights, it is shrouded in the mists of history, in that age when slow-moving ice sheets crept down over a warm and friendly world, driving the birds to the southlands, or in a later age when the ice

cap drew back leaving them to press toward the northlands. Now the highways are quite definitely established, and one feathered flock after another drives on through the wide areas of the sky as if its members were following a charted lane, familiar at every turn. While still an unsolved mystery, the yearly disappearance and later reappearance of the birds at the turn of the seasons made a nine-days' wonder, accounted for by many strange tales. Some thought they dropped into the mud and hibernated there; others claimed that they dived into the water at the horizon's edge and dwelt underseas for many months. But who would have stretched his imagination so far as to picture the long journeys, the tropical homes, the return trips, often along other routes from those already traveled, and all the other incidents of the fascinating narratives told us nowadays by naturalists who have kept accurate records of routes and yearly time-tables? As in many other cases, the wonder deepens with the increase of knowledge.

A SINGLE EXAMPLE — THE GOLDEN PLOVER

Let us take a single example, the migration story of the golden plover, shown in part on the accompanying map and described and accounted for by two authorities, H. W. Henshaw and Wells W. Cooke, both of the Biological Survey of the United States Department of Agriculture, to whom we are indebted for most of our information as to highways and time-tables.

The golden plovers breed on the "barren grounds" above the Arctic Circle, far beyond the tree line. They arrive there in the first week of June. Lest, perchance, you are deceived by the name "barren grounds" and are picturing the regions of the Arctic Circle as a region without charm or comfort for any sensible bird to seek as a breeding ground, let me quote to you Ernest Thompson Seton's description of these "Barren Lands of the North," from his book "The Arctic Prairies," in which he tells of a canoe journey of two thousand miles taken in the far northwest of Canada. Seton got there later in the season than the golden plover, for in June the lakes are still icebound, and the plovers build their shallow nests in the moss only a few inches above the frozen ground. But this is the region that is springing into life as the golden plover arrives.

"How precious and fertile the ground is made to seem, when every square foot of it is an exquisite elfin garden . . . filled with dainty flowers and still later embellished with delicate fruit. One of the wonderful things about these children of the Barrens is the great size of fruit and flower compared with the plant. The cranberry, the crowberry, the cloudberry, etc., produce fruit any one of which might outweigh the herb itself. . . . I never before saw such a realm of exquisite flowers so exquisitely displayed, and the effect at every turn throughout the land was color, color, color, to outdo the finest autumn tints of New England as the Colorado Canyon outdoes the Hoosac Gorge. What Nature can do only in October, elsewhere, she does here all season through, as though when she set out to paint the world she began on the Barrens with a full palette and when she reached the tropics had nothing left but green. Thus at every step one is wading through the lush grass or crushing prairie blossoms and fruits. It is so on and on; in every part of the scene, there are but few square feet that do not bloom with flowers and throb with life; yet is this region called the 'Barren Lands of the North'."

As soon as the young are old enough to make the trip, some time in the month of July, the fall migration begins by a flight to the Labrador coast, where the plovers fatten for a time on crowberries and other native fruits which are abundant in Labrador at this time. They must store fuel for their engines, for they are soon to make the longest continuous flight in the world, —twenty-four hundred miles at a single stretch without alighting on the way. This flight is not from Labrador but from Nova Scotia. From Labrador they make the short trip across the Gulf of St. Lawrence, which brings them to Nova Scotia. Then they "jump off" for this extraordinary flight over the ocean to northern South America. If the weather is fair they can be seen flying past the Bermudas and the Lesser Antilles, on to the larger islands and the mainland, accomplishing the whole twenty-four hundred miles without pause or rest. The trip has probably taken forty-eight hours. They fly steadily by night and day, in contrast to most migrants which fly at night and rest by day or

GOING SOUTH! THE

TIDAL BIRD WAVES OF THE FALL MIGRATION

fly by day and rest by night. But their journey is not over yet. Their chosen winter resort is in Argentina in the region of the river La Plata, twenty-seven hundred miles southward on the southeastern coast of South America. To it they make an overland trip, arriving in September. Here they remain during the summer of the Southern Hemisphere, from September to March, dwelling at their ease on the pampas, the vast treeless plains of Argentina, free from any family cares. The native birds of Argentina are nesting at this time and bringing up families, but no wayfarer from the north ever nests in the south. From their arctic breeding grounds to Argentina they have covered a distance of eight thousand miles.

Then in March comes to each bird the mysterious inner Nature summons to go north and rear a family. How it comes no one knows, but at the given time the birds start north. The six months' vacation is over. But now they go by a wholly different route, which you can trace out in part on the map. They cut diagonally across South America, striking the Gulf of Mexico, reaching the United States along the coasts of Louisiana and Texas, and then move slowly up the Mississippi Valley, northward to British America, reaching the arctic breeding grounds again early in June. This return route is two thousand miles long, in contrast to the eight thousand miles of the southern route. During the year they have covered ten thousand miles. In the process they have made the twenty-four hundred mile flight, the longest continuous flight known for any bird.

HOW THIS DOUBLE ROUTE WAS WORKED OUT

How did the plovers come to follow this roundabout double route? Why do they keep to the long downward route when the short upward one has been discovered? Wells Cooke gives this answer to those questions, an answer which goes back into the history of times before all the earth was habitable. When the ice began to recede from the continent of North America, the birds gradually were able to find food all along the way up the Mississippi Valley by a fairly direct route, and so came to cut off distance there on the return flight when they were in haste to get to the breeding grounds of the arctic. Hence, the direct northern route. When the ice had receded so that the great areas of Canada and the northern lands were opened up to the birds, there was opened up a great new region with excellent food supply. Labrador, which would have been shrouded in mists and chilled by cold winds in the spring, proved to have in the summer a most satisfying table spread from which the young birds and the old might partake. From Labrador they must get to South America. At first they would make the great westward curve to New England and follow the more usual land routes; but gradually ocean flights were attempted and were successful. The earliest ocean flights were doubtless short, with stops at the islands or digressions to the mainland; but gradually the birds found they could do the long, direct flights successfully, and at last the present direct line to South America was laid out, and this highway is followed yearly by hundreds of golden plovers. Food supply, weather conditions, and habit are, then, the determining factors which in long centuries have prescribed this course.

WHY CERTAIN ROUTES?

"If the whole area from Brazil to Canada were a plain with the general characteristics of the middle section of the Mississippi Valley," writes Wells Cooke, "the study of bird migration would lose much of its fascination. There would be a simple rhythmical swinging of the migration pendulum back and forth, spring and fall. But much of the earth's surface between Brazil and Canada is occupied by the Gulf of Mexico, the Caribbean Sea, and parts of the Atlantic Ocean, all devoid of sustenance for land birds. The two areas of abundant food supply are North America and northern South America, separated by the comparatively small land areas of Mexico and Central America, the islands of the West Indies, and the great waste stretches of water. The different courses taken by the birds to get around or over this intervening inhospitable region are almost as numerous as the bird families that traverse them." Yet there are certain well-established routes followed by groups of families, several of which are indicated on our map.

There is the water route to the extreme east,

the outside line of which is taken by the golden plover, while thousands of water birds take a slightly more westerly line with more frequent stops from Nova Scotia southward to South America. There are two routes which are only moderately popular from Florida by way of the islands of the sea over to South America. They are excellent from the point of view of short flights with frequent landings, but the islands visited can offer little in the way of food in proportion to the myriads of birds which throng the more frequented ways. So we come, traveling westward, to the middle route, thronged even on the map with feathered travelers, the route from northwestern Florida and western Louisiana across the Gulf of Mexico to the southern coast of the Gulf (Yucatan to Vera Cruz), and thence by land through Central America to South America. Probably more individuals, it is said, follow this route than all the other routes combined.

Look at your map and you will see how the routes converge at the Gulf of Mexico. "The birds east of the Alleghany Mountains move southwest in the fall, approximately parallel with the seacoast, and apparently keep this same direction across the Gulf. The birds of the central Mississippi Valley go southward to and over the Gulf. The birds between the Missouri and the edge of the plains and those of Canada east of the Rocky Mountains move southeastward and south until they join the others in their passage of the Gulf. In other words, the great majority of North American birds bound for a winter's sojourn in Central or South America elect a short cut across the Gulf of Mexico in preference to a longer land journey by way of Florida or Texas." Millions of birds cross at the widest part, which means a single flight of from five hundred to seven hundred miles.

Still farther west are the routes taken by the land birds from the western United States which winter in Mexico and Central America. Their trips are comparatively short; many stop in Mexico for the winter months.

Now that we have traced the usual routes and have the highways fairly well in mind, let us follow a few of the winged travelers on their journeys. The little blackpoll warblers make a tremendous cross-country trip. It seems, at first look, surprising that most of the birds that breed in Alaska migrate to the eastern United States; but when you examine the map you will be reminded that a part of Alaska lies east of the Rocky Mountain system. This mountain wall the birds do not cross. But east of it they travel whither they will. The blackpoll warblers want to go to northern South America, to Colombia, in all probability. See how straight they lay their air line across country to Florida and thence by one of two southern routes to the southlands. The mourning warbler takes another diagonal from Mexico and Texas across the long land route till it flies over water to Nova Scotia.

SHORT JOURNEYS AND LONG

"The length of the migration journey varies enormously," says Professor Cooke. "A few birds, like the grouse, quail, cardinal, and Carolina wren, are non-migratory. Many a bobwhite rounds out its full period of existence without ever going ten miles from the nest where it is hatched. Some other species migrate so short a distance that the movement is scarcely noticeable. . . . Most migratory birds desert the entire region occupied in summer for some other district adopted as a winter home. These two homes are separated by very variable distances. Many species from Canada winter in the United States, as the tree sparrow, junco, and snowflake; others nesting in the northern United States winter in the Gulf States, as the chipping, field, Savannah, and vesper sparrows, while *more than a hundred species leave the United States for the winter and spend that season in Central or even in South America.* Nor are they content with journeying to northern South America, but many cross the Equator and pass on to the pampas of Argentina and a few even to Patagonia. . . . *Nineteen species of shore birds breed north of the Arctic Circle, every one of which visits South America in winter*, six of them penetrating to Patagonia, a migration route more than eight thousand miles in length."

THE WORLD'S MIGRATION CHAMPION

This is the title that Professor Cooke gives to the arctic tern, the world's most extraordinary

Photo by Wm. L. Finley and H. T. Bohlman

STUDIES IN BIRD FLIGHT — GETTING A START

This is the first of a series of remarkable photographic studies of bird flight made by Mr. Finley. The white pelican is using the feet to get a start in rising from the water.

traveler. This tern is well named "arctic," for it goes from pole to pole. It nests "as far north as land has been discovered; that is, as far north as the bird can find anything stable on which to construct its nest. Indeed so arctic are the conditions under which it breeds that the first nest found by man in this region, only 7½° from the pole, contained a downy chick surrounded by a wall of newly fallen snow that had been scooped out of the nest by the parent." Explorers have found it "wintering" in the antarctic summer in 74° S. latitude. The tern is the only bird which flies from one polar region to another. The distance between the two farthermost points at which it has been observed is eleven thousand miles. In the year it travels, therefore, twenty-two thousand miles at the least estimate.

What the tern's route from pole to pole is no one knows. "A few scattered individuals have been noted along the United States coast south to Long Island, but the great flocks of thousands and thousands of these terns which range from pole to pole have never been noted" by men competent to keep the records. They

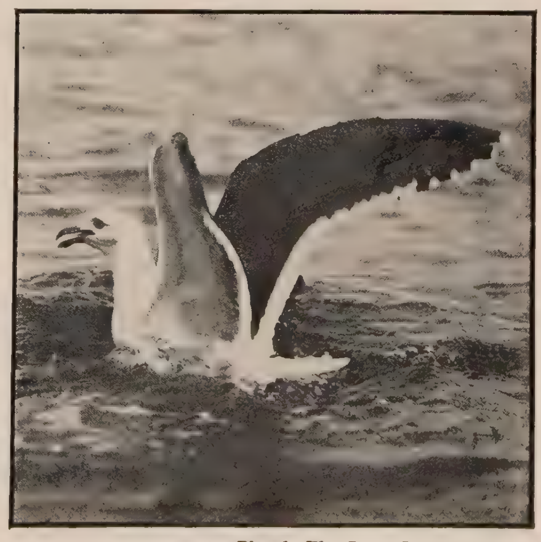


Photo by Wm. L. and Irene Finley

GULL ABOUT TO RISE

arrive in the far north about June 15, stay fourteen weeks at the nesting site, and leave in late August. They probably stay a few weeks longer in the far south than in the far north. "This would leave them scarcely twenty weeks for the round trip of twenty-two thousand miles. Not less than one hundred and fifty miles in a straight line must be their daily task, and this is undoubtedly multiplied several times by their zigzag twistings and turnings in pursuit of food." Almost the circumference of the globe in twenty weeks of flying!

Photos by Wm. L. Finley and H. T. Bohlman

CASPIAN TERNS IN FLIGHT — THE LONG WING ON THE UP AND DOWN STROKES

DAYLIGHT SAVING DE LUXE

We human beings may think that by getting up a little earlier or going to bed a little later we adapt ourselves cleverly to the sun's time, but what of a bird that travels from pole to pole at the times required to give it more hours of daylight and sunlight than any other animal on the globe? That is the way the arctic tern manages its life. "At the most northern nesting site the midnight sun has already appeared before the birds' arrival, and it never sets during their entire stay at the breeding grounds. During two months of their sojourn in the antarctic the birds do not see a sunset, and for the rest of the time the sun dips only a little way below the horizon and broad daylight is continuous. The birds therefore have twenty-four hours of daylight for at least eight months in the year, and during the other four months have considerably more daylight than darkness."

HOW FAST DO THE BIRDS GO?

We have noted a few instances of long flights made in a surprisingly short time. Migrating birds are not flying their fastest, Professor Cooke tells us. Their speed is usually from thirty to forty miles an hour and rarely exceeds fifty miles. Flights of a few hours on one night, then a rest for a day or two, then another flight, make the spring advance very slow. Day migrants fly less swiftly than night migrants. All must capture their meals en route. The arctic tern can make its record-breaking passage because a banquet is spread for it on the open waters over which it flies; yet time must be taken to pick up the food and eat it, — to stoke the engine with fuel, as it were.

The bird's engine is very economical of fuel, a vast improvement on any airplane invented by man. Less than two ounces of fuel in the shape of fat suffice to force the golden plover over its twenty-four hundred mile ocean course in forty-eight hours or less. A thousand-pound airplane, if as economical of fuel, would consume in a twenty-mile flight not a gallon of gasoline but a pint! The humming bird, smallest of all birds, flies five hundred miles across the Gulf of Mexico in a single night.

Birds that have long journeys to make travel faster than those that can afford to take a leisurely way, and many birds speed up as they get farther northward on their trip. Robins are an interesting example of varying speeds. They adapt themselves to the advance of spring along their routes. The western robin, due to breed in Alaska, appears in the Mississippi Valley in late February, and works slowly up at a rate of perhaps thirteen miles a day, on the average, through the states of Iowa and Minnesota; but when it gets up to southern Canada and near Alaska it may go fifty or even seventy miles a day, seeking to reach Alaska by the middle of May. It has spent ninety days on the trip. Meanwhile the blackpoll warbler, whose

Photo by Wm. L. Finley and H. T. Bohlman

CALIFORNIA GULL WITH UPWARD STROKE OF WING

It is hard to believe that this is a photograph; the birds are posed as in a painting.

southward route can be traced across the map, has stayed comfortably in the tropics through February and March. It turns up in Florida about the twentieth of April, gets to central Missouri by May 1 (which the robins left two months earlier), speeds up to one hundred miles a day, and at the last three hundred miles a day, and fetches up in Alaska only ten days later than the robins which started in February. Again, the eastern robin which has Newfoundland for its goal has taken a leisurely course up the Atlantic Coast, waiting for the spring weather to keep ahead of it, and brings up early in May, after a journey at a rate of some seventeen miles a day, in Newfoundland, twelve hundred miles farther south than its energetic Alaskan relatives.

So the story might be continued with interesting items from the travel habits of almost every familiar bird. We have given the average dates and the main routes. But no average is without many variations and no route without many dangers. While the great procession goes on, hundreds of "early birds," caught in the storms of a late spring, perish by the way. Others fail to find food because of storms. Still others dash against the lights of the great lighthouses which spell safety to the mariner on the ocean but too often disaster to the migrating bird. Efforts have been made to screen the lights and by many devices make them safer for the flocks of night-moving travelers.

Accounts given in facts and figures of any great life movements are always in danger of turning marvelous incidents and events into mere records and tabulations. Before we turn from this story, let us have two word pictures of migration as it has been watched from especially good posts of observation.

Photo by Wm. L. Finley and H. T. Bohlman

A RUNNING START — CORMORANT, OR SHAG, STARTING FLIGHT OVER WATER

THE SPRING ARRIVAL

Henry Seebohm, an English naturalist, spent two seasons in the arctic, and reports his observations on migration. "Birds go to the arctic regions to breed, not by thousands but

by millions. The cause of this migration is to be found in the lavish prodigality with which Nature has provided food." And again: "I have called this district a paradise, and so it is for two or three months of the year. Nowhere else in the whole world can you find such abundance of animal and vegetable life, brilliant flowers, birds both of gay plumage and melodious of song, where perpetual day smiles on sea and river and lake. For eight months or more, every trace of vegetable life is completely hidden under a thick blanket which absolutely covers every plant and bush." He then describes the gradual melting of the snow cap surrounding the north pole for about two thousand miles in every direction, as it melts at the rate of about four miles an hour on the circumference. This melting belt is "crowded with migratory birds eager to push forward to their breeding grounds — hurrying over the melting snow so long as the south wind makes bare places soft enough to feed on, but perpetually being driven back by the north wind, which locks up their food in its ice-chest." For

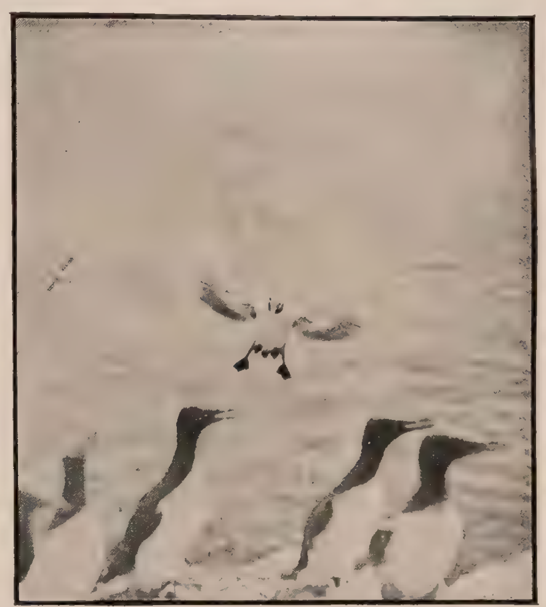


Photo by Wm. L. Finley and H. T. Bohlman

CALIFORNIA MURRE LANDING

The wings are moving so fast that they are blurred even in this snapshot. Study this photograph carefully to see how the head is bent against the body and how the feet are placed.

Photo by Wm. L. Finley and H. T. Bohlman

PELICAN LIGHTING

He looks like a drum major, marshaling his flock.

two weeks the battle between summer and winter continues. Then the ice goes. "Winter is finally vanquished for the year, and the fragments of his beaten army are compelled to retreat to the triumphant music of thousands of song birds. . . . It is incredible how rapidly the transformation is completed. Twelve hours after the snow had melted the wood anemone was in flower, and twenty-four hours after the yellow flowers of the marsh marigold opened. . . . The first rush of migratory birds across the Arctic Circle was almost bewildering, every piece of open water and every patch of bare ground swarming with them, a new species arriving every two hours for several days. . . . During the next fortnight the migration was prodigious."

IN THE FAR NORTH

On Mr. Seton's arctic trip he watched the starting southward of many migrants in the autumn. Here is one night's record: "That night (October 15) there was a dull yellow sunset. The morning came with a strong north wind and rain that turned to snow, and with it great flocks of birds migrating from the Athabaska Lake. Many rough-legged hawks, hundreds of small land-birds, thousands of snow-birds in flocks of 20 to 200, myriads of ducks and geese, passed over our heads going southward before the frost. About 8.30 the geese began to pass in ever-increasing flocks; between 9.45 and 10 I counted 114 flocks averaging about 30 each (5 to 300), and they kept on at this rate till 2 P. M. This would give a total of nearly 100,000 geese. It was a joyful thing to see and hear them; their legion in flight array went stringing high aloft, so high they looked not like geese, but threads across the sky, the cobwebs, indeed, that Mother Carey was sweeping away with her north-wind broom."

HOW HIGH DO THEY GO?

Flocks of migrating birds have been observed from lighthouses, where the air all about and as far up as could be seen was filled with the flap and the whir of moving wings. They have been observed on the field of a telescope and their height and speed calculated as they flew rapidly across the field of the lens. During the war a British ornithologist saw migration from a new vantage point He was flying in his airplane among the migrating birds. He passed a flock of golden plovers at a height of more than a mile, some six thousand feet. When he was flying at ninety-five hundred feet he saw birds above him, and with the aid of powerful glasses identified them as swallows. He met a carrier pigeon at twenty-five hundred feet altitude. On the whole it seems probable that most normal bird migrations take place far above the human range of vision except in the case of the extremely small bird. Certainly birds can and do fly at amazingly high altitudes. It is scientifically proved that they may fly at fifteen thousand feet. Aviators will doubtless give us much new information in the coming years.

In such numbers do the bird armies pass on invisible highways of the air far above our heads for many nights of the year. Even the familiar visitors in our woodlands and gardens have probably spent the winter in the tropics and are on their way to northern regions which we who welcome them have never seen. With all we know of their routes and time-tables there are many questions yet to be answered. Bird migration is hardly less a mystery now that it has been thus charted out and laid before our wondering eyes. We may say that besides its keen sense of sight the bird must have a special sense of direction to keep it on its course. But of that sense of direction and its workings we know very little. We may say that food marks out the path; but how does the bird know so unerringly the food route of other years or even of past centuries? Habit, instinct, sense of direction — we need them all to even try to account for the seasonal travels of these feathered "globe-flyers," and when we are done, we can only ask, not answer, the poet's questioning as to

> "Who calls the council, states the certain day,
> Who forms the phalanx, and who leads the way?"

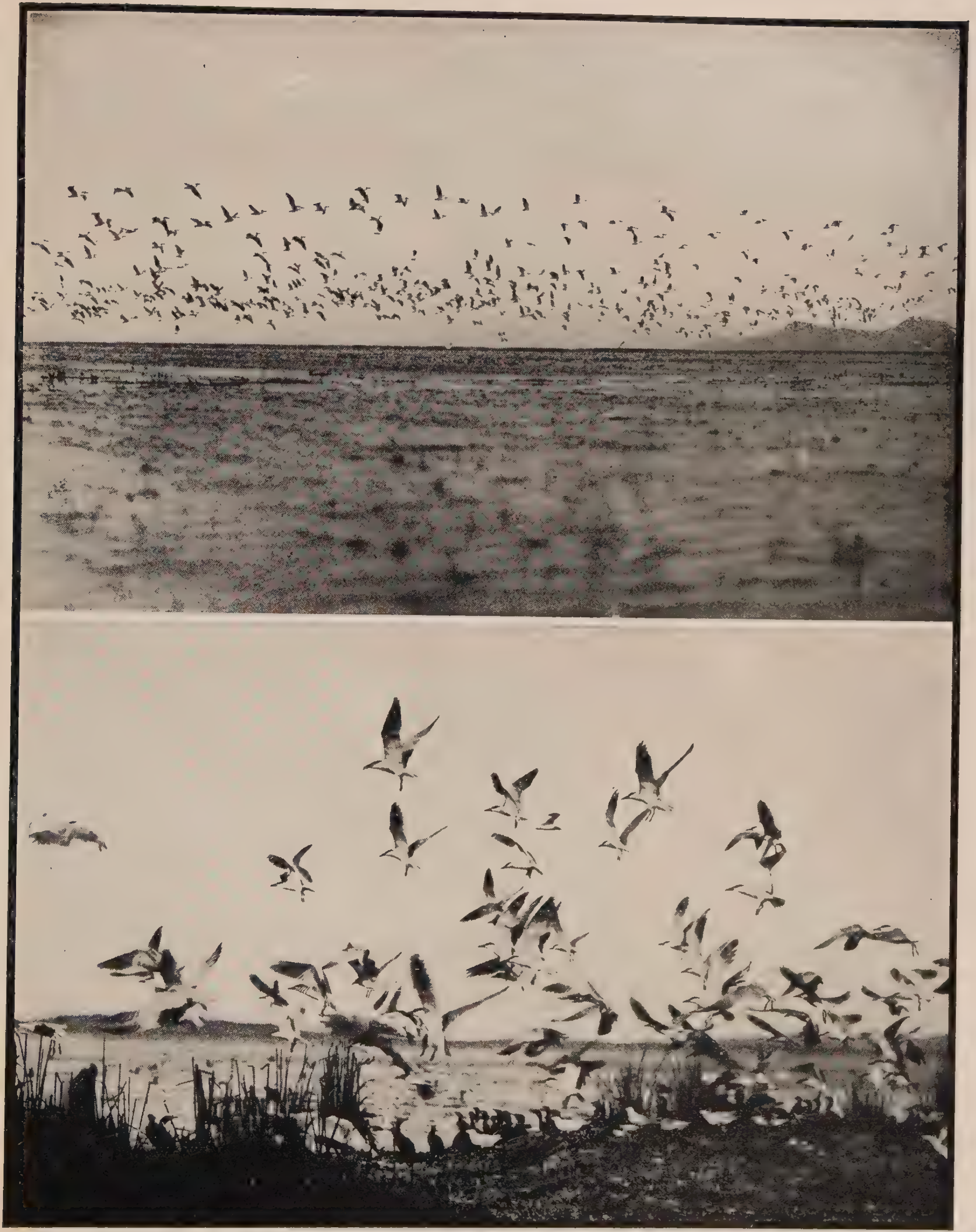


Photo by Wm. L. Finley and H. T. Bohlman

ON THE WING

"There is a Power whose care
Teaches thy way along that pathless coast, –
The desert and illimitable air, —"

BRYANT

HOW DO THEY KNOW?

Of mind in its beginnings in the lower creation — of homing birds — of instinct as it appears in insects — of increasing intelligence in animals.

IN these four words is summed up the puzzle in man's mind as he watches the lower animals: *How do they know?* The bird finds its way over the highway which centuries of travel have made traditional for its kind. It starts from the southlands at the proper time, so that it will appear year after year in the same spot on approximately the same date. How does it find the way? How does it know when to start? It builds a nest after the pattern used by its parents and grandparents and ancestors of long past days. How does it know how to go about it? The young spider throws out its thread and goes about the skilled engineering task of framing a web as if it had done it a hundred times; indeed, it is said that young spiders build better webs, for older ones grow less careful. How do they know? The oil-beetle larva, which never had any experience of a bee, catches on to the bee that visits the flower into which it has climbed, rides on that bee to the honeycomb and so gets its needed food, bee's egg and honey. What instinct guided it to perform those particular acts of catching hold and letting go at the right moments? The examples are beyond number. Already we have had many of them in the stories of this volume. Here we shall group a few more, with which to end our study of the lower animals before we turn to the story of man. Even the plants present puzzles which we cannot solve.

HAVE PLANTS ANY CONSCIOUSNESS?

Bergson thinks that a plant which has retained or gained the power of movement may have some degree of consciousness. "The humblest organism," he suggests, "is conscious in proportion to its power to move *freely*." When plants chose to stay still, they wrapped themselves in a protecting coat of stalk and stem through which no messages could easily reach them from the outer world, and consequently, by his idea, *went to sleep*. Animals left themselves open to any stimuli that might come to them from the world about them, and *became more and more wide-awake*. But if a plant has some power of movement, what then? It may have some vague consciousness, according to Bergson; to quote his own words, consciousness "probably awakens in the vegetable that has regained liberty of movement, and awakens in just the degree to which the vegetable has reconquered this liberty." This is an interesting idea, and one worth following up and applying to the strange plants that have kept surprising powers of movement.

Take the plants that catch and eat insects, for example. The Venus's-flytrap will reject almost at once a stone which it has taken into itself by mistake. It seems to recognize that this is not the food it desires. Automatic action? Probably, but is there something more?

The sensitive plant, shown in the picture, is one of the plant wonders over which scientists have long been perplexed. It makes a quick response, not only at the point touched, but all over the plant almost immediately upon being touched. In the lower half of the page it is photographed with its leaves spread in normal fashion. The tip of one leaf is touched, and the effect is that shown in the other half of the page. Every leaf has closed almost instantaneously. A slight movement of water at the base of the leaf causes the drooping in each separate leaf; but does that explain the response all over the plant? An animal makes a similar quick response to an outside stimulus because its nervous system carries the message. This plant seems to have its protoplasmic life-stuff so developed or so delicately balanced that a slight movement in one part is transmitted to every part of the plant. But what is the nervous system of the lower animals but specialized protoplasm?

DO PLANTS HAVE FEELINGS?

Photo by E. F. Bigelow

THE SENSITIVE PLANT: BEFORE BEING TOUCHED (below) AFTER BEING TOUCHED (above)

Has this plant nerves? It it has not, how does it happen that if the tip of one leaf is barely touched, within a few seconds every leaf ot the whole plant closes tight? Somehow the story of that tiny touch is carried to every part of every leaf. In animals and humans we should say this showed some kind of a nervous system. This is one of the most wonderful plants ever discovered.

Photo by S. Leonard Bastin
TELEGRAPH PLANT — BY NIGHT

Another interesting point about the sensitive plant is that, like animals, it is powerfully affected by anæsthetics. Exposed to the vapors of chloroform or ether it gradually droops, just as if it were passing from consciousness to unconsciousness. An electric shock will agitate it greatly. Also it appears to get "tired" if irritated too persistently and will not make any response for a time. It was shown in an earlier chapter that the sleep movements of plants were probably automatic. Perhaps all responses may be explained chemically and physically; but certainly the sensitive plant stands out above all others for its great speed of shock transmission.

There is another plant, the telegraph plant of India and Ceylon, which has a surprising trick of movement. The sensitive plant responds to touch. The telegraph plant keeps up a set of movements spontaneously, on its own

Photo by S. Leonard Bastin
BY DAY — WITH ARMS EXTENDED

account, without requiring any outside stimulus. The telegraph from which it took its name was of an ancient pattern like our block signal system, or like "wig-wagging," in which signs were conveyed by the movements of arms or signboards. This plant, like other members of the pea family, has three leaflets on a single base. You will see them in the picture of the open plant,— one very large, the other two very small. It is these tiny leaflets that are in almost constant movement. They revolve or jerk up and down, once in every two or three minutes, in a veritable orgy of wig-wagging. The movement of the large leaf is not so conspicuous; at night it drops down so that its tip points alway towards the earth. Touch or any outside stimulus makes little or no impression on the plant. Its movements are of its own originating and fit some mysterious life plan of its own.

RIGHT OR LEFT

Mr. Bastin has sent to us the accompanying photograph, which illustrates a curiously persistent act of choice on the part of climbing plants. Some plants in winding about a pole climb to the right and wind from right to left; others turn always to the left. The bean vine is following its custom in turning to the right; the hop vine does just the opposite. Why should one start always to the right, the other to the left? No one knows.

HOMING BIRDS

Homing pigeons have served as men's messengers for two thousand years or more. Now we are being given the results of some most interesting experiments on other homing birds. Professor John B. Watson and Dr. K. S. Lashley have been making tests with terns (noddy terns and sooty terns), tropical members of the gull family in the Gulf of Mexico. These experiments are so interesting that I am going to give them in some detail. The problem is how animals — in this case these terns — find their way home from remote spots or under uncommonly baffling conditions. Do they have a mysterious homing instinct? Do they have a sense of direction which man does not possess to the same extent? Are they guided by temperature? by magnetic currents? by memory? by sight? by smell? by telepathy? Every one of these theories has been advanced. These two investigators set themselves to make as careful tests as could be devised. They have not yet solved the riddle, but they have made some interesting contributions to it.

THE STORY OF THE TESTS

Bird Key is a little deserted mound of sand about three hundred yards in diameter lying in the middle of the Gulf of Mexico, a member

Photo by S. Leonard Bastin

CLIMBING VINES

The bean turns to the right, the hop to the left.

of the Tortugas group. It was especially well suited for these tests, for to it migrate about the first of May from twenty-five to thirty thousand noddy and sooty terns, tropical gulls which have spent the winter in the Caribbean Sea. This is as far north as they ever go. They are therefore known to be unfamiliar with the regions beyond. Here they spend their entire

nesting season. Professor Watson studied their habits until he made sure that even on their flights for food they do not go out over the water more than fifteen or eighteen miles. They are, moreover, wild birds, wholly untrained. No inherited experience or previous adventures in homing entered to complicate the tests.

The methods employed were these: After the egg is laid, male and female take turns in brooding. One is therefore always found on the nest. In the absence of one of the pair, the other will preserve the nest as a "home" to which to return. At nesting time it is not difficult to capture birds. Then each is marked individually with large streaks of different-colored oil paints, each bird receiving its own particular pattern. Next the nest is tagged to show the date when the bird was removed.

Professor Watson began during his first summer at the island with taking birds short distances and setting them free. All the birds returned. Then he took five properly marked birds, put them in a cage, and gave them into the charge of Dr. H. E. Jordan, who was returning to New York. Dr. Jordan left Bird Key June 13th by government tug, carrying the birds by boat to Key West. There food was purchased for them (small minnows), and at 3 A. M. on the 14th he boarded the boat leaving Key West for New York. The birds were put in the hold, watered and fed. Two days later, on the 16th, at 9 A. M. the birds were released at a latitude and longitude approximately twelve miles east of Cape Hatteras. By a direct line over the water they were about eight hundred and fifty miles from Bird Key. If they took the "alongshore route," as was more likely, since these terns neither fly at night nor swim nor rest on the water, although they depend on the ocean for food and for the sea water which they drink, they had between one thousand and eleven hundred miles to travel. On the 21st of June, at 8.30 A. M., Professor Watson found two of the birds at their nests and later a third. As the birds which remained at home had in at least one case taken other mates, it seemed not unlikely that the other two had returned, found their nests tenanted, and lost themselves from his notice in the great bird colony. At any rate these three had covered the distance in from five to six days.

This was a very severe test of homing. There was no doubt that the territory was wholly unknown. There were no landmarks which could be sighted, recognized, and followed. The great problem in homing has always been, must the pathway be familiar? For homing pigeons, trained in this way, it frequently is. Here it was not. It would seem that some special sense must have been called into play.

TRYING AGAIN

Another summer, Professor Watson tried other experiments. The point had been raised that the birds had instinctively followed the coast line southward to warmer climates until they came within range of their home, then located it without difficulty. That is, they had returned as the first birds migrated, in response to a temperature control. This time the birds were taken and put on a steamer bound for Galveston. This was an over-water trip of eight hundred and fifty-five miles. Ten birds were released when the vessel was five hundred and eighty-five miles out; of the ten, eight returned to their nests. Two were released in a driving rain, at night, seven hundred and twenty miles out; both returned. Twelve were released in Galveston Harbor; only three returned. This last record was not surprising, as the birds were in poor condition by the time they reached Galveston. They had suffered under the conditions of captivity, resenting them greatly, and had had in the end to be forcibly fed. Some of them undoubtedly made an easy prey for the vigilant hawks of the harbor regions. The records had shown, however, that these birds would return from six to eight hundred miles across wholly uncharted and unfamiliar wastes of water, with no shore line visible.

Galveston is about the same latitude as Bird Key; so there could be no question of seeking warmer climes. There could have been no visual landmarks. Even if the birds flew very high, — and they do fly low, — they would have to be a mile up in the air to see an ordinary landmark such as a tower one hundred miles away. To see any such object when two hundred miles away they would have to be three miles up; and so on, in increasing ratio. The

air would be too rarefied and the temperature too low for even moderately high flights. So the theory of visual landmarks could not hold. It was interesting that as soon as they were liberated the birds with one exception started east. This one started west, flew some two hundred yards, then wheeled sharply and flew east.

Again we ask — How did they know?

A FABRE INSECT STORY

Jean-Henri Fabre, the great French naturalist, has written volumes of interesting observations on the insect world. From his book, "The Wonders of Instinct," we take a single example of the perfection of instinct. The capricorn grub, which will turn at last into a beetle, spends three years in the trunk of an oak tree. During all this period this little grub wanders lazily about in the wood, boring for itself a passage and eating the wood through which it tunnels. In all this devious tunneling it does not go far from the inner depths of the tree, where it can keep warm and safe. But the day approaches when the worm will turn into a beetle. "Urged by a presentiment that to us remains an unfathomable mystery, the grub leaves the inside of the oak, its peaceful retreat, its unassailable stronghold, to wriggle toward the outside, where lives the foe, the woodpecker, who may gobble up the succulent little sausage. At the risk of its life, it stubbornly digs and gnaws to the very bark, of which it leaves no more intact than the thinnest film, a slender screen." This will be the exit hole by which the beetle-that-is-to-be will get out into the open air in which it must spend its short life. The beetle will not be able to bore its way out, as the grub can. It will not be able to get out through the tunnel used by the grub, for it will be too big a creature.

Photo by Wm. L. Finley and H. T. Bohlman

VARIED THRUSHES FIGHTING ON SNOW

When the grub has prepared this exit with only the thinnest layer of bark to cover it, back

it goes down its gallery a little way and digs "a transformation-chamber more sumptuously furnished and barricaded than any that I have ever seen." This chamber, three or four inches long and an inch high, is "padded throughout with a fine swan's-down, a delicate precaution taken by the rough worm on behalf of the tender pupa. . . . When the exit-way is prepared and the cell upholstered in velvet and closed with a three-fold barricade, the industrious worm has concluded its task. It lays aside its tools, sheds its skin," and goes into the sleep from which it will emerge a beetle.

During this entire period it is utterly helpless and defenseless, "weakness personified," but see how carefully the grub has provided a safe, sheltered, luxurious chamber. One more item is to be noticed. The grub lies down with its head toward the door. This may seem a trifling detail; but it is all important for the future. The wormlike grub can turn and twist itself round in the chamber or the tunnel, but the coming beetle will have a horny armor. "He will not even be capable of bending. . . . He must absolutely find the door in front of him, lest he perish in the casket. Should the grub forget this little formality, should it lie down to its nymphal sleep with its head at the back of the cell, the capricorn is infallibly lost: his cradle becomes a hopeless dungeon." But this does not happen. The grub lies down facing head out, and wakes as a beetle from sleep, makes an easy way out through a roomy gallery to the thin screen of bark, pushes it out, and comes into the open.

But what of this grub? Only a worm, with very poor equipment except to bore wood; yet what does it seem to know? "It knows that the coming beetle will not be able to cut himself a road through the oak and it bethinks itself of opening one for him at its own risk and peril. It knows that the beetle, in its stiff armor, will never be able to turn and make for the door of the cell; and it takes care to fall into its sleep with its head to the door. It knows how soft the pupa's flesh will be and upholsters the bedroom with velvet. . . . It knows the future with a clear vision, or, to be accurate, *it behaves as though it knew it.*"

This is only one of hundreds of instances. The carpenter bee prepares a five- or six-room apartment and stores each cell with food for the young which it will never see. Most of the lower creatures, insects, ants, bees, wasps, of the so-called "little-brain" type, perform these amazing feats of instinctive behavior. Again we ask. How do they know?

DO THEY KNOW?

"At attention" is Mr. Finley's title for the photograph of a young heron on the opposite page. We saw how Nature is able to throw around its creatures by skillful use of shapes, colors, lights and shades a mantle of invisibility. To this they often add a self-protection by pose which they seem to adopt instinctively. Not only is this heron following the rule of safety by keeping absolutely still; he has adopted a pose so like the position of the branches among which he stands as to furnish an additional safeguard. At a distance this still figure will be comparatively inconspicuous.

The opossum "plays dead," either from nervous terror, as some naturalists insist, or by intention to deceive. There is no question but that in the higher animals some measure of "animal mind" enters in. Careful experiments are being carried on year after year to see just how much is habit, how much instinct, how much imitation, how much memory, and so forth. Certainly intelligence increases as we follow life up the scale. Does instinct decrease as intelligence increases? It might seem so. Bergson puts it picturesquely when he says that there is "no instinct that is not surrounded with a fringe of intelligence."

Let us close this section, on "Each after Its Kind," as we began it, with the words of Sir Oliver Lodge, which after this long reading we are better able to understand and appreciate. "I regard life," he says, "as the rudiment of mind. Life as it ascends the scale blossoms into mentality, mind. It may blossom into spirit."

AT ATTENTION

Photo by Wm. L. Finley and H. T. Bohlman

YOUNG HERON POSING IN IMITATION OF LIMBS OF TREE

Why does he do it? Does he know that by taking this pose and holding it, he renders himself comparatively inconspicuous at a distance? Granted he does it, how did Mr. Finley manage to get his portrait in this pose?

WORLDS WITHIN WORLDS

Of matter, which is the stuff with which life works — of the newer knowledge about worlds which lie beyond the microscope — of molecules, atoms, and electrons, and the part which they play in our lives — of untold stores of energy which man may some day tap.

ALL through this volume we have talked of two great outstanding facts in the world — life and matter. "The Wonder of Life" has lain in the marvelous results it could get in the handling of matter. Now we are going to discuss this stuff with which life works, — matter. We are going to find that the materials with which life is working are almost as wonderful as life itself, — almost, but not quite, for life stands supreme, with a magic power beyond competition. But life as we know it on this planet works only through matter. We shall come back to life's miracles with a better appreciation after we have seen what marvelous stuff it has at hand for its molding and shaping. This is a very different kind of story from any other story in the volume. It is a very modern story, for it could not have been told ten or fifteen years ago; yet it is a very old story, for these thrilling facts about the make-up of matter which man is only beginning to find out have been true since the earth was formed.

Two things we all enjoy doing: taking things apart to see what they are made of, and putting things together to see what can be made from them. The small boy wants to take the watch to pieces to see the wheels go round; the cook likes to take flour, sugar, eggs, and butter and stir them together to make a cake. It is the same very human and natural instinct that has given us most of our knowledge of the world in which we live. Lately this knowledge has progressed in certain fields by leaps and bounds. Above everything else man has always wanted to know what the world is made of and how its "wheels go round." To-day he is nearer knowing it than he has ever been before. As you read this story of the marvelous discoveries made in the last ten, twenty, and thirty years, and even in the last two or three years, remember that to you is being told, almost as a matter of course, the answer to a riddle which the wisest men of other days were never able to solve.

HOW THE DOORS WERE UNLOCKED

In the old fairy stories the youth who was seeking his fortune used sometimes, you remember, to be given a key. This would unlock a door; but when he had opened that door he would find himself not in the presence of the treasure he sought, but in another room with another locked door before him. It was for him to search this room diligently, to break its spell by some act of his, and find the key by which he might unlock its door. Often he would go through ten or twelve rooms, solving the mystery of each, before he came finally to the inmost door beyond which the treasure lay within his reach.

Such has been the way of the scientist in his search for the hidden mystery of the matter of which the universe is made. In this quest one man's lifetime was not long enough to finish the journey. Indeed, the journey is not finished yet, nor perhaps will it ever be. But down through the centuries the way has been followed. One door after another has been unlocked, one group of men taking up the search where an older generation laid it down, until to-day within our time keys have been found in such rapid succession that the progress from room to room has been surprisingly swift.

To-day it is possible for you to jump over all the centuries, to be carried by a single leap of thought into the last room that has been opened, the room where the secrets of the universe have

come almost if not quite within the grasp of our human knowledge. Now, in another minute, you are to go into a new Wonder World, a world of which you have perhaps never dreamed, the world of molecules, atoms, and electrons.

GETTING READY

To make the mind journey into these startling regions of Molecule World, Atom World, and Electron World, we must follow a custom of the fairy stories. We must feel ourselves and our eyes and our mental pictures becoming smaller and smaller and smaller. The favorite limit in the old stories was for a mortal to feel himself shrinking till he was "no taller than an inch." If I were you, I should be ready to shrink even after that, until I was a thousandth, then a ten-thousandth, then a hundred-thousandth, then a millionth of an inch tall. That would be a comfortable size, I think, for this mind journey. Are you ready? Then we 're off.

IN A DROP OF WATER

Of an imaginary visit to find out its secrets.

THE first world we shall visit is a drop of water. All these worlds within worlds into which you are going are very lively places. If you stepped right into them, you might be whirled off your feet so quickly that you would not have a moment to look about you. So before we take the first plunge, let us stop for a moment and peer cautiously in.

ON THE RIM OF A DROP OF WATER

The first drop of water into which we will look is a drop of ordinary water, with mineral matter in it and living bacteria in it. Water is too convenient a common carrier and too ready to act as a solvent, as you know, to be found frequently in Nature without some foreign matter besides its hydrogen and oxygen (H_2O). Remember that you have made yourself very, very small, so that a drop of water will seem very large. As you look into this great round sphere of liquid, your eye must first become accustomed to the rapid motion of all things in it. When you look at a wheel which is being whirled very rapidly, you see only the revolving rim. The spokes do not show at all. They are practically lost to sight because they are turning so swiftly. So in the drop of water, first you see a great swirling motion of something — you can hardly tell what. Your eye has been changed by the same magic which reduced your size, so that it can see things as it could not in real life. As your eye gets accustomed to the rapid motion, you begin to see these living particles of which we spoke, bacteria, darting about, each a tiny living creature with a motion of its own.

But look! besides these bacteria there are smaller objects. The drop of water is full of them. See that one there! it started to go toward us, but before it could get far another or a dozen others hit it and drove it back or sidewise or up or down — it is hard to see which. So in the instant it did not really get anywhere at all, but just bobbed up and down, driven back and forth in a small space by these dozens upon dozens of tiny objects, like marbles, which are darting about.

By the time you have looked into this drop of water awhile, you forget that it is a drop of water at all. If you have really succeeded in wiping off the slate of your mind every idea you ever had of what a drop of water was like, and you should be asked as you peer into this curious world to tell what you see, you might answer in somewhat this way: that this is a space full of tiny marble-like objects driving about like mad — millions of them, you should judge — and that floating about between them are great big things, which are being tossed about in the whirlpool of these smaller marble-like bodies.

Then your scientist-guide might say: Those big things are bacteria (which you may be more likely to call, in popular phrase, germs) and bits of dead matter, both of which get into all ordinary water. But the tiny darting objects are

what you are interested to see, for they are the water itself. But water, you might reply, is a liquid. You are familiar with water; it is not like that. Ah! that was all you knew about it when you were seeing with your human eyes, when you were a full-sized human being. Now you are really seeing a drop of water, for you are tiny enough to look at it from the inside. Those little darting marbles are molecules. A drop of water is a world of molecules. The word "molecule" comes from the Latin word *moles*, meaning "mass," to which is added the diminutive ending to give the meaning of smallness; so it means, literally, "little mass of matter."

IN A DROP OF PURE WATER

This drop of water into which you have been looking was not pure water because of the living and dead matter in it. All natural water has some foreign substances in it. But let us imagine a drop of water which has been distilled and purified until it is pure water, water with nothing but hydrogen and oxygen in it.

We will stand no longer looking on, hovering upon the rim of the drop. We will plunge into the midst of it. Because we are in it the motion does not seem so swift. Unless you look out of the window of a moving train, you do not realize how fast the train is moving. Ask your guide how fast that hydrogen molecule which just hit you, or the one on which you are riding, is moving. "Oh! perhaps at the rate of a mile a second, perhaps not quite so fast," he will reply calmly, as though a mile a second were quite an ordinary rate of speed. "But how far do they get at this rate?" "Perhaps a quarter of a millionth of an inch, before they hit one of their neighbors." "But if they are going so fast, how often do they hit each other in a second?" "That varies with different sizes of molecules," he would say, "but as you can see or rather feel for yourself by the way you are dancing up and down at this instant, they are hitting each other all the time."

Suppose just at that moment, in spite of all your resolutions, that you were going to forget the big, stable world where you had lived before you became so tiny, suppose you are getting a bit dizzy and upset by this tremendous rate of speed. "Would you like me to slow it down a little?" your wonder-work'ng scientist-guide might inquire. If you admitted that you would be only too thankful to have things slowed down a bit, he might waye his wand and freeze that drop of water. Gradually, as it became colder and colder, the molecules would begin to slow down in their motion until, when it was frozen, the rate of speed would be much, much less than when they were making up a drop of liquid water. They would fall into what would look to you like layers, lying in far more regular order, and simply vibrating back and forth within short limits.

"This," your guide would tell you, "is a solid. It is a solid because the molecules are lying closer together."

But possibly this bit of ice, for all the comfort of its greater stability and less confusion, might not please you for a long stay. After you had examined it you might feel that there was no room here, that you were confined, that the molecules pressed in on you too close. Then, quick as lightning, he might wave his wand and set the molecules dancing more rapidly, — faster, faster, even faster than they were in the first place, and farther and farther apart as they danced. There might even be bits of time when no molecule hit you as you stood in their midst. "Now the water has become steam. You are in the midst of a vapor. See how far apart the molecules are. That is what happens when water is heated. The molecules fly apart. Now you are in a vapor."

Then, if he were wise, he would wave his wand, this time over you, for you would have seen as much as you could take into your mind in one trip. You would feel yourself becoming larger and larger, till you were your natural size again. Then you could sit down and think it all over, and find out what you had learned on this trip into Molecule World as it is found in a drop of water, a bit of ice, or a mass of steam.

It is because solids are made up of molecules, and because we can speed up or slow down the motion of these molecules at will, that we can use for our comfort the raw materials which lie about us. The cook uses this power in melting butter.

THE STORY OF MOLECULE WORLD

Of matter as made up of molecules — of their effect in our lives.

MOLECULE WORLD is the world next below the range of the microscope. With the microscope we can see bacteria and germs; we can see matter, as it is made up of a great many molecules put together. But the molecule itself is too small for us to see. How do we know it is there? There are a dozen different ways to prove it. Of some of them you will learn later. But suppose now we just believe it, as all the wise men of science do, and listen to what they have to tell us about it.

When scientists began to "take the world apart," to see what it was made of, they split up substances, and split them up, and split them up, until finally they found that every substance had a unit size beyond which if you still tried to split it up you got, not the substance itself but something different, something that behaved differently under the influence of heat, or turned a different color, or in one or a dozen of the ways in which chemists make tests, showed that it had changed, that it had lost the properties (characteristics) which it formerly had.

They decided that they had come to the bottom of the scale. They had traveled back through all the numbers to One. Here was the molecule, the unit mass, the smallest particle of each substance, which was the actual substance itself. They began to study these molecules, and they found out some of the things which you have just found out on your journey into a drop of water.

A SOLID IN MOLECULE WORLD

Molecules of which there are thousands upon thousands of kinds, are at ordinary temperatures always in motion. On their rate of motion depends the state of a substance, whether in our rating it is a solid, a liquid, or a gas. In a solid the molecules come fairly close together. They are in ceaseless motion, but their range of motion is limited. They are tied, anchored, in a given region.

That they are moving it is easy to prove. Put a block of gold in contact with a block of lead and leave them touching each other. In time traces of the gold will be found in the block of lead, traces of lead in the block of gold. The molecules have moved over.

WHEN A SOLID BECOMES LIQUID

If solids were "solid," if they were not made up of molecules but were in reality the thick chunks of matter which they appear to be, most of our factories and all of our kitchens would have to go out of business. It is because solids are made up of molecules, and because we can speed up or slow down the motion of these molecules at will, — because, in short, of our power over bits of matter too tiny for us to see, — that we can use for our comfort the raw materials which lie about us. The cook uses this power when she melts butter. The foundry man uses it when he applies heat to iron and then adding carbon makes it into steel.

Any one who by applying heat to a solid turns it into a liquid is speeding up the motion of molecules. By speeding them up he is sending them farther apart. When in a solid the motion gets so rapid that the molecules are driven out of whatever order they were in and begin to dart out in every direction, wandering around one another at random, that substance has ceased to be solid and become liquid. They were not in ranks before, unless the solid was crystallized, but now they have become a pushing, jostling crowd. The rate of motion has become swift enough to overcome partially the mutual attraction that held them in certain relations.

The number of molecules in one drop of water has been estimated at a million million million millions. All these molecules are in violent motion.

The solid lump of ice has, for example, been turned into liquid water.

FROM LIQUID TO GAS

If the heat is still applied the molecules keep on moving faster and faster. Those near the surface of the liquid soon begin to go so fast that the pull of their companions is not sufficient to keep them from escaping into the surrounding air. More and more escape. Steam is rising from the surface of the water; the liquid, in this case, is changing into a vapor. (We say "vapor" here instead of "gas" because steam happens to be a "gasified liquid." But this is a technical use of terms which is more a matter of degree than of kind.)

In a gas, like oxygen or hydrogen, molecules have a good deal of space between them. Sometimes a molecule will travel several hundred times its own diameter before it hits another molecule. The crowd is marching more freely, each member of it being less likely to be impeded in his path by collisions.

PRACTICAL POINTS

In the light of this knowledge it is easy to see why the law holds good which we learned from physics textbooks that "heat expands" and "cold contracts." Freezing brings the molecules gradually closer together. The surface area of the frozen body will be smaller than that of the liquid. (Water, as you know, is the exception to this rule. As water approaches its freezing point, it increases in volume; hence, ice floats.) Heating sends the molecules farther apart. This driving apart is responsible for the bursting of a steam boiler. The water is turning to steam so rapidly that the walls of the boiler cannot resist the pressure of the molecules outward. Therefore we regulate the "pressure" on our boilers and do not let it get too high.

The next time you see a steaming teakettle, think of the molecules that are finding freedom from being packed so closely together and are darting out into the wide world. The next time you smell an odor, think of the molecules that are being diffused through the air.

"If we imagine the molecules as each one an individual kind of balloon, and all of them bobbing around loose, with nothing to hold them together but as though striving to keep as far as possible from one another, they are in the state of a gas. If we imagine them as skipping around every which way, over and under one another, sideways, forward, and backward, but held down by a greater tension, we may say that the body which they constitute is in a liquid state. When they clinch we have a solid. Even then they continue in motion, dancing around all the time."—Ellwood Hendrick.

IN ATOM WORLD

Of matter as it consists of less than a hundred elements.

MOLECULE WORLD is a place where we could stay a lifetime, watching movements and changes of which we have only begun to tell. To understand Molecule World we must go a step further and study what molecules are made of, which takes us into Atom World.

To take molecules apart and find that they are made up of atoms is like taking words apart and finding that they are made up of letters. It is as if one looked at the dictionary and said, "All those words, and each different from the other! And thousands upon thousands of them! It is too hard. I give it up. Such a complicated thing as language I can never understand." Then some one comes along and says: "But see! look at those words carefully. Do you notice that they are all made up of letters? All the words in the dictionary are made up from just twenty-six letters." Then it would not look so difficult to get at the plan on which language is built.

Scientists stopped at the molecule as the unit mass of each substance, because if they went further, they found that the fractions of matter which they obtained had different properties from the original substance with which they had begun. Atoms are different from molecules; so are letters different from words. Atoms are the letters which make up the thousands of molecule words, and the atom alphabet has, at the present moment, ninety-two letters. (This number may be increased by new discoveries,

but if you remember that the number is between ninety and one hundred you will be safe.) Even if letters do not have "meanings" as words do, they have properties of their own, and they are very different one from another. No one would mistake the letter *a* for the letter *b*. No chemist would mistake one atom for another. Yet these atoms in spite of their separateness and individuality fall into groups or families.

Pause for a moment to think what this so-called "atomic theory" of matter means. It means that everything in the world is made up of atoms, that all the different substances are made from combinations of ninety-two or so elements, put together in millions of ways.

Think what unending labor it took to find this out. Every substance had to be tested, weighed, treated, studied, until it was proved that they could all be traced back to this "matter alphabet."

WITHIN ATOM WORLD

Atom World seemed about as far as man was likely to be able to go in his investigations. Here were particles some three-hundred millionths of an inch wide, or thereabouts. (This is the diameter of the smallest, says Comstock, and the largest cannot be many times this.) Surely he had done wonders to be able to find them, to weigh them, to measure them, and to build up a whole science of chemistry on their behavior. Patiently he had used this new key to knowledge and had split up every known molecule. He had found that the water molecule had two hydrogen atoms to one oxygen, hydrogen and oxygen being elements; and water had become by his formula, H_2O, a symbol to express this fact. A sugar molecule, on the other hand, was a long, difficult "word," with twelve carbon atoms, twenty-two hydrogen atoms, eleven oxygen atoms, a word of forty-five letters, three letters being repeated each a fixed number of times. This would read, by his system of symbols, $C_{12}H_{22}O_{11}$. The matter dictionary had been arranged "alphabetically," so to speak, each molecule being put in its place with its proper spelling. Now that you know how to read these chemical symbols, you will realize how simple they are and yet how full of meaning. Nowhere in written language is a story told in such brief space. Each group of letters with its figures, like $C_{12}H_{22}O_{11}$, tells a story of a world in which the separate constituents are so infinitesimally small as to be beyond the reach of even the most powerful microscope.

IN EVERYDAY LIFE

When a writer knows the meaning of words he can make sentences. The laying out of this "matter dictionary" has had tremendous practical results. When the chemist knew of what atoms each molecule was composed and in what proportions they occurred, he could put molecules together intelligently to make the combinations he desired. He could manufacture dyes or poison gases or food substitutes or drugs or soaps or any one of the chemical combinations of molecules on which we depend in our daily life. Molecule World, which includes within itself Atom World, is no remote, separate creation of the scientist's imagination, but a world of familiar everyday operations. It has a whole science of its own, chemistry, which is "the science that treats of the composition of substances and of the transformations which they undergo." Of its place in modern life Ellwood Hendrick has written in a fascinating book, which every one who has an interest to go further along these lines should read, "Everyman's Chemistry." "Chemistry," he says, "is not only the intelligence department of industry; it is everywhere, and we cannot get away from it. Every kitchen is a laboratory, every baker is a chemical manufacturer, and every butcher is a chemical warehouseman. Chemistry washes us, launders our clothes, and bleaches and dyes them; it provides us with metals, with our morning paper, and with books; it helps the farmer to grow our food; and when it is all over, whether we be burned to ashes or buried in the ground, it is by chemical processes that our bodies go back again into the great order of things."

Interesting as these worlds are, we do not wish to stop even here, but will go on into a smaller world, a world within Atom World, the newly discovered Electron World. Only in very recent years have we been able to know that as a molecule is built up from atoms, so an atom is

in all probability built up from still more minute single particles, which because of their relation with electricity are called electrons. Science did wonders to reduce the world to a least common denominator of ninety-two elements. Now it is looking into the inside of those atoms and saying that they in turn seem to be made up of not more than two primal elements, positive and negative electrons.

TWO POSSIBILITIES

We have been talking about journeys, mind journeys, into a drop of water, into Molecule World and then into Atom World, journeys which we have made very swiftly, clearing at one leap all the centuries of study and investigation in which scientists made those slow advances. We could jump right into Electron World. If you would prefer that way, all you have to do is to skip the next pages and begin to read again on page 317. But the progress especially of the last twenty years has been so interesting and the ways in which the discoveries have been made are so thrilling that I am hoping you will want to follow along step by step. After all, the fairy-tale youth appreciated the treasure in the inmost room far more because of all the tasks he had done and the keys he had hunted out on the way. The next pages are for the people who wish to go, albeit quickly, through the inner rooms of the last twenty years.

ELECTRICITY COMES IN

The key which unlocked the door of the world within Atom World was electricity. Electricity has always been a mystery; it is a mystery still. We make it our servant; we ride in trolley cars, we are summoned by electric bells, we read by electric light, and we run our factories by electric currents.* But how little we really know about "this double-headed genie which we summon from the world of magic and mystery by rubbing our Aladdin lamp"!

> *The fairyland of science lies beyond the microscope in "worlds within worlds" which are being explored in this twentieth century. This fairyland is no remote region but the very world in which we live.*

It is surprising how recent is all our electrical knowledge, both practical and theoretical. Benjamin Franklin was the first man to engage in serious speculation about what electricity was and to advance a workable theory about it. The Greeks had found that amber when rubbed attracted to itself light objects. A scientist of Queen Elizabeth's court had noted that amber was not the only substance which could take on this property. A glass rod when rubbed with silk had the same attracting quality, as had also about twenty other substances which he identified. To this change which took place he gave a name, saying of the glass rod that it was "electrified," or literally, according to the derivation of the word, "amberized," the Greek word for amber being "electron." This scientist, whose name was Gilbert, lived about 1600 A.D. In 1733 a French chemist discovered that while sealing wax rubbed with fur seemed also to be electrified, the effect produced by its presence near certain other bodies was exactly opposite to that produced by the silk-rubbed glass rod. What the glass rod attracted to itself, the fur-rubbed sealing wax repelled; what the rod repelled, the sealing wax attracted. This was the first time in history when the two electrical states or the two forms of electrical "charge" were even noticed.

FRANKLIN'S THEORY

From our modern vantage point it is easy to forget how great the pioneer scientists really were and what wonderful flashes of insight they had. This information was all Franklin had on which to build. Yet in the middle of the eighteenth century, 1747 or thereabouts, Franklin, recognizing the two kinds of electrical phenomena, named them, in a moment of inspiration, "positive" and "negative." To be sure, he did put the labels on the two kinds in exactly the opposite way from that which we should use to-day, for from our greater knowledge we think that the negative is the leading phenomenon. Franklin had nothing to guide him, so he called

* See Volume II, pp. 45–84.

the type on glass rubbed with silk "positive," and the type on sealing wax when rubbed with fur "negative." The insight was shown in his grasp of the essential unity of the electrical phenomena. Those names represented Franklin's own theory of electricity. He assumed that there was something which he chose to call the electrical fluid or "electrical fire" which existed in normal amounts in all matter. "The electrical matter," he says, "consists of particles extremely subtle, since it can permeate common matter, even the densest, with such freedom and ease as not to receive any appreciable resistance." There you have the first expression of the electron theory of the twentieth century. It is one of those interesting cases where a master mind leaps all the obstacles and, with no basis of experimental data to support it in detail, grasps a truth. "He unquestionably believed," says Millikan, "in the existence of an electrical particle or atom." When Franklin wrote that, "he could scarcely have dreamed that it would ever be possible to isolate and study by itself one of the ultimate particles of the electrical fluid." Yet that is just what certain scientists, notably Professor Millikan, in his laboratory in Chicago, have been able in this twentieth century to do.

WHAT DIFFERENCE DOES IT MAKE?

Why are we interested in one theory or another about electricity? It makes a difference in all the pictures that we have in our minds of the world in which we live. We are interested to know what matter is made of; we have traced it, with the scientist, down through molecules and atoms. That resolved the world into ninety-two or so elements. There science might have had to stop; but it would not have been a very satisfactory stopping place, for the question was, how did there come to be the ninety-two kinds of atoms? What were they made of, and why or how did they differ one from another? Then, all at once, another line of investigation into another mystery, namely, what electricity was, brought scientists face to face with what seemed to indicate that the answer to the one riddle would be likely to give the answer to the other. Electricity was being traced back to actual electrical particles instead of being treated as some mysterious force with no physical properties whatsoever. But to show, as they found themselves showing at one and the same time, that electrons are constituents, probably *the* constituents, of the atom is to come within speaking, dreaming distance of the wonderful idea that the whole world may be built of combinations of particles of negative and positive electricity, held together by their own marvelous forces. If that be true, then all masses,— the sun, the moon, the stars, earth, air, and water, — everything in this vast universe is formed originally from the same two primordial substances. When untouched by life, they form "dead matter"; when animated by life, they make up the living creation.

What difference does it make? I am going to let you have an answer to that question given by Professor Millikan in the introduction to his book, "The Electron." "And now this twentieth century . . . has already attempted to take a still bigger and more significant step. By superposing upon the molecular and the atomic worlds of the nineteenth century a third electronic world it has sought to reduce the number of primordial elements to not more than two, namely, positive and negative electrical charges. Along with this effort has come the present period of extraordinary development and fertility. . . . The results of yesterday's researches, designed for no other purpose than to add a little more to our knowledge of the ultimate structure of matter, are to-day seized upon by the practical business world and made to multiply tenfold the effectiveness of the telephone or to extract six times as much light as was formerly obtained from a given amount of electric power. . . . These are indeed matters of fundamental and absorbing interest to the man who is seeking to unveil Nature's inmost secrets, but they are also events which are pregnant with meaning for the man of commerce and for the worker in the factory. For it usually happens," and this is

> *"It usually happens that when Nature's inner workings have once been laid bare, man sooner or later finds a way to put his brains inside the machine and to drive it whither he wills."*

the part of Professor Millikan's answer which will interest particularly readers of OUR WONDER WORLD, "for it usually happens that when Nature's inner workings have once been laid bare, man sooner or later finds a way to put his brains inside the machine and to drive it whither he wills. Every increase in man's knowledge of the way in which Nature works must, in the long run, increase by just so much man's ability to control Nature and to turn her hidden forces to his own account."

THE ELECTRON APPEARS

To return to our story of how these mysteries were unlocked: Here were these particles of electricity darting hither and thither, and the human race had for thousands of years gone about its business unconscious of their presence. Then one day an electric current was passed through a tube from which the air had been partially exhausted. If the air had been left in the tube, the current would not have passed through easily. Air is, fortunately for us, a very poor conductor of electricity. But this vacuum tube proved to let the current through it easily, and as the current went through, there appeared in the tube something like a beam of light with dark spaces between. No one who is not a scientist can appreciate what an event that was. Here was the mysterious energy, electricity; here was a partially empty tube. Electricity was turned into it, and there appeared a mysterious, unevenly sectioned beam of light. The physicists fell upon that tube and worked over it as a dog would worry a bone. Some of them found out facts about one little section and some about another, until those sections are now named for the men who made discoveries about them, just as countries are named for their explorers. Books might be written about what was learned of electricity from those partially empty tubes. What you and I are interested in is that here for the first time the electron was recognized. Shooting out from the plate where the current left the tube were actual beams unlike anything observed before. To them Sir William Crookes gave the prophetic name "radiant matter." That was in 1878. These rays are now known to be streams of negative electrons.

HOW DO THEY KNOW?

When any one gives us exact measurements about these things which are so far below the range of sight, the natural question is, How do they know? For instance, we are told that an electron has an apparent mass one eighteen-hundred-forty-fifth the mass of a hydrogen atom — and a hydrogen atom was measured in hundred-millionths of an inch! Let me give you in a very sketchy way the story of some of the experiments by which such measurements are made and checked up, beginning with those of J. J. Thomson, one of the pioneer and most brilliant investigators. Thomson tried out different gases in the tube and found by tests that the particles were identical, regardless of the nature of the gas. This showed that here was a new kind of matter. Then a magnet was brought near the tube, and the stream of light was deflected from its regular course just as a searchlight might be swung round. This response to a magnet showed that the particles carried electrical charges, for an electrical current can always be swung around by a magnet. In dealing with magnetism and electricity he was on the familiar ground where known laws applied. He could measure how far the stream of rays was swung out of its original course, compare this with the strength of the magnet used, and work out by a law of physics the mass of the particle. That was the way he got the mass, as quoted above.

Then he wished to know how much electricity each particle carried. He measured the amount of electricity he was putting through the tube. That was simple, for it was under his control. The next step was to discover how many particles there were carrying this current. If he could find that out, he could divide the amount of the charge by the number of particles and find out how much each one was carrying. If one hundred pounds of sugar were carried by boys, each of whom carried an equal amount, he must find out how many boys there were before he could know how much each one was carrying. If there were one hundred boys, each one would carry one pound; if twenty boys, each one would carry five pounds; if ten boys, each one would carry ten pounds. That was the line of reasoning. But how count the particles?

Counting particles too small to be seen is a task you or I would not covet. Thomson hit on a most ingenious scheme for doing it. It had been observed that if there were particles of dust in the air and the air became overmoist, each particle of dust would act as a center upon which to condense a tiny droplet of water. Then it had been found that an electrical particle would act as a center for moisture in the same way that a particle of dust would. He introduced into his testing apparatus a known amount of moisture. The moisture condensed into droplets. He counted the droplets, and was thus able to estimate roughly the number of particles.

Do not think for a moment that important scientific data rest on a single experiment like the one which I have been describing. All kinds of experiments and calculations have been made and checked. When they all agree, then the facts are credited. This is told simply to show you that there is proof, and that these tales are not of wild imaginings, or even of visions like that of Franklin, but are reports from accurate experiment and mathematical calculation.

ELECTRON EXPLOSIONS

When electrons were located in vacuum tubes, liquids or gases, they did not appear until the substance had been heated or something else had been done to it. There was no spontaneous discharge. Then radium was discovered: other radioactive substances were located. In the meantime X-rays were discovered. All your life you will be coming upon different chapters of the story of the wonderful opening up of scientific possibilities through the discovery of X-rays and radioactivity. Wireless telegraphy followed closely in the wake of this new knowledge, as did many other scientific inventions. Our interest is that from radium there were shooting out negative electrons, positive particles, and some sort of X-ray radiations. The indivisible atom of the nineteenth century was gone. It was exploding before our eyes.

IN ELECTRON WORLD

Of matter and electricity — of matter as a storehouse of energy.

EACH world into which we have peered is our own world, the world in which we live. We are only looking deeper and deeper into its mysteries. We are seeing it as if it were a thousand or a million times bigger, or as if we were so much smaller. Dr. Langmuir has put these relative sizes in a way that makes them vivid to us. "If a lump of ordinary matter the size of a baseball could be magnified to the size of the earth, the atoms in it would then have become about the size of baseballs. In other words, an atom is about as big compared to a baseball as the baseball is when compared to the earth." That is Atom World. Now for Electron World.

INSIDE AN ATOM

An atom at close view is very different from what we should have expected. At least, after traveling down the scale of matter so far, my own expectation would have been that one would come in the atom to a fairly solid little particle. But an atom is not like that at all. Like the doughnut of comic-journal fame, an atom proves, when you get near to it and look into it, to be mostly "hole." "Now," some one may be saying, "you are really going too far. You have taken me down the scale through molecules which were too small for me to see, and atoms which were still smaller parts of molecules. And now you tell me that an atom is mostly 'hole.' I protest. The world is made up of something. I know it is." Certainly the world is made up of something, but there may be a most amazing amount of space between the somethings, in proportion to their sizes. The solar system is made of something, even though there is an enormous amount of space between us and the sun, and between us and the other planets.

An atom is built somewhat on the solar-system plan. It has a very tiny, wonderfully powerful center, a nucleus, as it is called, the size of which

is infinitesimal even when compared with the diameter of the atom. Then it has electrons, in different numbers for different kinds of atoms, grouped in some way in the space around that nucleus. The force within the nucleus in the center holds those electrons in their places or revolving in their orbits, in some such manner as the sun holds the planets of our solar system (including our own earth) in their appointed courses. But there is this difference: the solar system remains intact, keeping its same planets century after century. The atom loses outer electrons and gains new ones. Electricity "happens," as we might express it in a very unscientific way, or better, electrical phenomena which can be detected take place when some of the electrons escape from the orbit of one atom and fly off into the orbit of another atom or go dancing around in space. You remember how we remarked that if solids were really "solid" and not made up of molecules, we could not cook or manufacture or do a great many other necessary things. If atoms were "solid" and each atom kept its own electrons, the world would probably just stop going: that is all. So our whole world runs as it does because it is an Electron World. That makes it worth while to find out a few things about electrons, does it not? First, let us take some phenomena with which we are quite familiar and describe them in terms of electrons.

WHAT IS AN ELECTRIC CURRENT?

Every one of us has asked that question at some time. When during a storm a tangle of wires is blown down from the poles to which they were fastened, some of those wires are likely to be "live" wires, that is, wires through which an electric current is passing. Others are ordinary wires, with nothing mysterious or dangerous about them. What is happening in the "live" wire?

> *What is electricity? An electric current in a wire is a stream of electrons moving through that wire. A battery is an "electron pump" which forces the stream through the wire.*

An electric current in a wire is a stream of electrons moving through that wire. Sir Oliver Lodge has pictured the passing of electrons from atom to atom like the passing up of buckets of water by a long line of helpers at a fire. In a solid, like wire, the atoms do not move about freely. So all they can do is to pass the electrons, as it were, from hand to hand, swinging a little in one direction to receive them, in another to deliver them. Good conductors of electricity are those in which the transfer of an electron from one atom to another is easy.

Why should the transfer be easier in one kind of atom than in another? Atoms are held together by some kind of strong force within them. Most atoms have many electrons in their outer orbits which may or may not be held with a very strong attraction by the atom. Some atoms have a tight grip on their electrons, others a very loose hold. The atom of a metal which is a good conductor of electricity will have such a weak attraction for electrons that there are vast numbers of electrons in a practically free state through the entire body of the metal. They can thus move very readily under the influence of an outside electrical force.

HOW FAST DOES ELECTRICITY TRAVEL?

Here we get help from another illustration, similar to the fire-bucket one, yet different. When the end of a long rope is pulled, the "impulse" travels the entire length of the rope, passed on "from hand to hand." This impulse may be simply described as the impulse to move. No single inch of the rope moves very far, but the impulse travels very rapidly. Even so "the electrons forming the electric current move very slowly, but they move in enormous numbers. . . . The far greater 'speed of electricity' is due to the fact that the impulse is passed on very rapidly from electron to electron, so that when the electrons at the rear end of a hundred-mile wire are set moving, those at the distant end are caused to take up the motion a very small fraction of a second later. . . . In the electrical case, the impulse to move travels with the speed of light, i.e., one hundred and eighty-six thousand miles a second, whereas the electrons themselves (i.e., the true electricity) move only a small fraction of an inch a minute."

The important fact to notice in this twentieth-century discussion is that an electric current is considered as "the passage of a definite, material, granular substance along the conductor." This is from the words of Professor Millikan, who adds: "In other words, the two entities, electricity and matter, which the nineteenth century tried to keep distinct, begin to look like different aspects of one and the same thing." He continues, "Have we any evidence as yet that all matter is electrical?" and answers, "We have *evidence*, but as yet no *proof*."

WHAT HAPPENS WHEN A BODY IS CHARGED WITH ELECTRICITY?

Franklin and his predecessors noted that there were two kinds of electric charges, positive and negative. They are explained in this way in Electron World. Positive electricity seems to exist only within the atom; negative electricity travels from atom to atom, appearing to exist only in the form of electrons. Therefore, the only way to give a body a negative charge is to put electrons on it or in it. The way to give a body a positive charge is to take negative electrons away from it until its positive character (due to its nucleus or positive center) predominates. To charge a body with electricity is to disturb its normal balance, either by adding electrons or by taking them away. A negative charge means that an atom possesses more than its normal number of electrons; a positive charge, that it has less than its normal number.

A BATTERY, AN ELECTRON PUMP

An electric battery has been cleverly characterized by Comstock as an "electricity pump" or an "electron pump." It does not create electricity. It is no factory. Its chemical action consists in the breaking up and re-forming of molecules. In the process millions of electrons are set free from atoms. The stream of these free electrons, as they are forced through the circuit of the battery, starts tremendous disturbances in the way of vibrations among the atoms. The stream is forced through the negative pole, travels around the circuit, and reënters the battery at the positive pole. The returning stream contains as many individual electrons as it had when it started. No electricity has been used up. But the stream has done its work. The vibration of the atoms affected appears as heat or light or whatever effects have been produced. What we pay for is to have the electrons pumped through the wire; it requires a battery or power plant to keep them going.

WHAT HOLDS THE WORLD TOGETHER?

We have been speaking of atoms as parting with their free electrons in a way that might seem to imply that atoms were very loose "solar systems," which let their "planets" go dashing off into other systems with complete unconcern as to their own self-preservation. That is not true. The electrons which are concerned are those on the outside ring, that is, the outermost "planets" of the system. The atom may well let these go easily, for it can as easily pick up others to take their places. Electrons are all exactly alike; one will serve as well as another. But when it comes to the real inner constitution of the atom we find no such conditions.

Fortunately for the stability of the world, atoms do not go to pieces easily. Within itself the atom holds a balance of forces, a guarantee of self-preservation, which is the world's guarantee of stability and equilibrium. Electricity tends always to equilibrium. The negative and the positive balance. An atom tends to equilibrium, appearing to outward tests electrically neutral. This might conceivably be due to a total absence of electricity, but we know now that it is due to the fact that while electrical charges are present, there are just as many positive charges as there are negative charges. It is a case of electricity in balance.

> *"If a lump of ordinary matter the size of a baseball could be magnified to the size of the earth, the atoms in it would have then become about the size of baseballs. An atom is as big compared with a baseball as the baseball is when compared to the earth." That is Atom World.*

THE INNER SANCTUM

The mystery of an atom is hidden in its nucleus, as is also the secret of its identity. Of this nucleus we know comparatively little. It is very tiny. "If we imagine an atom magnified until it has the diameter of one mile, the electrons would be about five feet in diameter, while the nucleus at the center would be only the size of an ordinary walnut." This nucleus is strongly positive, positive to a definite number of unit charges, the number varying with different atoms. A hydrogen atom has, for example, a positive excess charge of one. It has therefore one electron (negative) to balance this charge. A helium atom has on its nucleus an excess positive charge of two; it has, therefore, two electrons to balance it. Atoms of carbon have six electrons, of oxygen eight, of aluminum thirteen, of sulphur sixteen, of iron twenty-six, of copper twenty-nine, of silver forty-seven, of gold seventy-nine, of lead eighty-two, of radium eighty-eight.

WHEN ATOMS EXPLODED

If no atom had ever exploded, we might never have known how much energy there was concealed in an atom. "The explosive or radioactive atom has given the secret away," writes Lodge. "All atoms possess energy, but some cannot hold it all. These are radioactive elements, and they periodically fire off projectiles with more than volcanic violence. A radium atom firing off a particle . . . is like a two-ton gun firing off a hundred-pound shot. . . . The speed with which an alpha particle is ejected is about one-fifteenth that of light — sufficient to carry it from London to New York, if there were no obstruction, in a quarter of a second. Its energy is therefore, weight for weight, a million times that of a bullet." A milligram weighs one-thousandth as much as a gram, and it takes about twenty-eight grams to make up an ounce-weight. Yet a milligram of radium is firing thirty million projectiles a second.

"If we imagine an atom magnified until it has the diameter of one mile, the electrons would be about five feet in diameter, while the nucleus at the center would be only the size of an ordinary walnut." That is Electron World.

THE ALCHEMIST'S DREAM

The old alchemist, mixing weird concoctions in his evil-smelling pot, had one outstanding ambition, to find the process by which one element could be turned into another. If only lead could be turned into gold! Men were almost ready to sell their souls if perchance they might gain thereby the secret of a process by which they might transform the whole world.

The twentieth-century scientist has seen such a miracle performed. He has seen radium firing off alpha particles which when tested proved to be particles of helium with a double positive charge of electricity. Radium is near one end of the scale with eighty-eight electrons, helium almost at the other with but two electrons. Knowing this fact, it is not so astonishing that the simpler element helium with its small positive charge might come out of the very complex element radium. But the point is that the long dreamed of event has taken place, — out of one element in its break-down have come particles of another element. Nor is this a single isolated example. We spoke of a radium atom firing off a particle, a positively charged atom of helium. "Before it has exhausted its ammunition it fires off five such projectiles, and then settles down into a quieter existence as lead — or, if not exactly lead, something chemically indistinguishable from lead. A uranium atom had already fired off four projectiles in order to become radium. Radium is a temporary half-way house between uranium and lead; it is active, but not so fiercely active as some of the intermediate substances, which last so short a time that they barely have names."

The dream that one element might change into another has been realized, but Nature alone has been the alchemist. Over chemical action, which involves attractions and repulsions *between* atoms and molecules, man has gained considerable control. But over forces *within* the atom and over the inviolability of the inner sanctum, the atom nucleus, Nature has stood guardian in sole control. Whether man will

ever be able to try his apprentice hand at making one element from another, it remains for the twentieth or twenty-first century to show. The guardian of the atom will doubtless hold its treasure in sufficiently safe keeping to safeguard the equilibrium of the world from being tampered with by man.

THE ATOM A TREASURE HOUSE

The atom is a great untapped reservoir of energy; and energy is literally what keeps the world going. We have seen how plants capture energy from the sunlight by means of their green chlorophyll grains and how the whole living creation depends on their continuing capture of that energy. Coal, which is one of our chief sources of energy, is the treasure house in which is stored the energy of forgotten ages. The dream of the twentieth century is to find some way by which atomic energy may be harnessed for practical utilization. The amount of energy locked up in an atom is immense, almost beyond computation.

IF AN OCEAN STEAMER WERE RUN ON RADIUM

To get any idea of the forces locked up in an atom, we turn once more to radium and watch the splitting up of its atom. As the radium atom sends out its projectiles it gives out an appreciable amount of heat. "Every ounce of radium gives out, each hour, enough heat to raise one ounce of water from freezing point to boiling. In the course of seventeen hundred years this ounce of radium will have given out as much heat as could be obtained from the burning of nearly four tons of coal, and there would still be half an ounce of radium left over. If we could stock a transatlantic liner with radium instead of coal, if we could persuade the radium to give up its energy as wanted instead of at its own snail's pace, then the thousands of cubic feet now given over to coal-bunker space would become available for cargo — the amount of radium required could be carried in a satchel."

Sir William Ramsay has given us another comparison. Could we procure a ton of radium, its energy harnessed to human uses would drive a ship of fifteen thousand tons with engines of fifteen thousand horse power at a speed of fifteen knots an hour continuously for thirty years. To procure energy for this undertaking according to our present methods would require a million and a half tons of coal. Such an amount of coal would, if piled up, make a pyramid more than sixteen acres in extent and as high as the dome of the Capitol at Washington.

But the total yearly output of the largest of the few radium-producing companies in the world is about an ounce. There are perhaps only seven ounces as yet redeemed from the ore in which it is hidden.* So it will be a long time before we do much work with radium. A substance is considered precious if it is "worth its weight in gold." Radium was, at the time of Madame Curie's visit to the United States in 1921, worth two hundred thousand times its weight in gold. It cost one hundred thousand dollars to buy the single gram (one twenty-eighth of an ounce) which was presented by the President as the gift of a hospitable and grateful people to her as the discoverer of radium.

If radium is so precious, how then, it might well be asked, can radio-luminous watches be sold for such low prices? Radium is so powerful that it can make luminous another substance, zinc sulphide, with which it is mixed for this purpose. A manufacturer tells us that a single gram of radium mixed with twenty thousand grams of pure quality of zinc sulphide will make enough luminous material to illuminate the dials of six hundred and sixty-seven thousand watches.

A CLOCK THAT WILL GO MORE THAN TWO THOUSAND YEARS

A clock has been constructed which is run by this energy. There is no question in the mind

A transatlantic steamship might make an ocean passage on the energy from a few pounds of radium and its products instead of its present enormous supply of coal if the energy of radium could be released in so brief a time and could be controlled.

* See Volume IV, pp. 406–410.

of the scientist — barring outward disaster to the mechanism by earthquake or fire or by the falling to pieces of its parts — this clock will be keeping time two thousand years from now. The radium will be doing its part if only the works of the clock can be kept harnessed to it. This, it may be said, is the nearest to perpetual motion of anything yet obtained. The clock will need no winding, because the atom is "wound up."

A LOOK AHEAD

Radioactive elements have called our attention to the vast stores of energy locked up in atoms. This energy is not confined to radioactive elements. They happen to be giving it forth in their break-down. Other atoms hold it and continue to be what they are. In a little finger there is said to be energy to run all the trains in the United States for a few minutes, if we could but release it. The high explosives in a shell or bomb are not to be compared with the terrific possibilities of the atoms of which any object is composed, provided its energy could be released and controlled.

We are inclined to agree with Sir Oliver Lodge when he says, "I hope that the human race will not discover how to use this energy until it has brains and morality enough to use it properly, because if this discovery is made by the wrong people this planet would be unsafe." Yet he thinks the time will come when atomic energy will take the place of coal as a source of power. As yet only the most complex atoms, those like uranium with its ninety-two electrons and radium with its eighty-eight, are giving off this atomic energy, while other atoms hold their identity. Moreover, even they break down only a short distance, so to speak, into other substances. We might well sacrifice a small portion of some of these substances if it ever proved possible to "harness" them.

IS THE WORLD BREAKING UP?

Any one following this line of thought and observing the break-up of elements comes naturally to the final question, Is the world breaking up? There is no question but that we have in radioactivity a transformation of more complicated elements into simpler ones which is in the nature of a world "decay" or disintegration. The furious explosions of these extremely rare elements have at last caught our sluggish human attention. They suggest the question, Is every element radioactive, did we but have wit enough to perceive it? It may be. But if it is, it takes two thousand years for some of these most explosive elements to half break down; for others it takes longer, though for some only days or hours or minutes. There is a long time element in most of these important and spectacular changes. There may also be, under conditions greatly differing from ours, a reverse process of building up now going on. This is mere speculation at present.

The answer to our question is, then, that if radioactivity is the sign of a gradual change in the condition of the elements, the processes of "breaking up" are so slow in ordinary matter as to be negligible over any ordinary term of years. Moreover to this very energy, generated by atom explosions in certain substances, the world owes much. It used to be predicted that the earth was going ultimately to cool down beyond the possible limits of temperature for human or other life. Perhaps it will. But the distribution of a very small amount of certain of these radioactive elements in the crust of the earth — such a distribution as there undoubtedly is — would easily give off enough heat to meet any present loss that the earth is undergoing. If the output of the sun in terms of energy is in any danger of giving out, as calculated from other lines of study, a comparatively small amount within the sun of the force within atoms which radioactivity shows to exist could easily make up for any deficiency. Radioactivity is, therefore, contributing needed energy. What might cause alarm on the one side seems to tend to allay alarm on another. We have a right to believe that the balance will be kept safe. With this assurance we may congratulate ourselves that we are living in the most interesting century from the scientific point of view that has ever come in the world's history, and that the scientists of our own generation have not only made great contributions to the sum of human knowledge but are probably on the brink of even greater discoveries.

Photo by A. Tennyson Beals

THE MACHINERY OF OUR BODIES

Of life as it fulfills itself in human beings.

WE have taken a long pilgrimage on the trail of life as it winds hither and thither, up and down the earth. We have followed its course through the worlds of earth, air, and water, and into the realms of bird, beast, fish, insect, and plant. Now we come back to the greatest wonder of all, life's highest creation,—the human being.

From this moment the point of view of the book changes. We have tried honestly and to the limit of our imaginations to put ourselves in the place of each lowly creature, and to see his life as it looks to him. We come back with renewed interest to our own lives. From this moment we are interested in "The Wonder of Life" as it shows itself in ourselves. We shall touch on animal life only as it illustrates some point of difference from or likeness to our own physical make-up. From all this varied touch with other life, we must bring for our help a better sense of proportion, a more intelligent and broader picture of life as it is lived in the wide world. Now we are surely justified in being for the remainder of this volume wholly, intensely, and frankly interested in ourselves and our fellow human beings, who are built on the same pattern. It is man that has been made in the image of God, man that has been crowned with glory and honor. We have a right to glory in our own powers, physical, mental, and spiritual. To this end we must find out more about ourselves.

THE BLOOD — THE RIVER OF LIFE

"Red, crimson, scarlet, hot, the river of life, the carrier of all that is good and all that is bad by its myriad streams through our bodies; the rarest, most precious, most gorgeous of fluids; the daughter of the salt ocean, finer and more worshipful even than the waters of the great mother, the sea, . . . such is the blood." — SIR RAY LANKESTER.

EACH one of us owns a river. It is not a very big river, only five or six quarts of liquid; but it is a very lively little stream, rushing along over its course at a rapid rate. It does not have a source or a mouth, as do the rivers about which we learn in geography. This is a closed stream. It runs around and around and around the same course day after day and year after year. But little as it is and shut in as it is, to you and me it is the most important river in the world, for it is our river of life. If the river of blood were to stop running through the body, life would cease.

Being a river — that is, a stream of free-moving liquid — it has the invaluable property of being an excellent common carrier. Each tiniest cell in the world, whether it is tucked away in the most remote and hidden part of a human body or floats alone by itself as does the independent little amœba, must have some relation with the outer world. It must take in what it needs for food; it must dispose of what it does not need as waste. The amœba gets for itself what it needs from its surroundings. For the cells within the great highly organized system of the human body, the river of blood acts as common carrier. It flows into almost every part of the body. It carries with it the food and gases which the cells need. It picks up waste materials and washes them away. It takes valuable freight from one part of the body to another.

THE RIVER AS IT IS PICTURED

This river of blood cannot keep itself swinging around and around the body at this rapid rate by its own force. A geographical river flows rapidly only as the water is rushing onward, downward, seeking its own level. In the human body the liquid must flow up and around and down, regardless of the position of the head, trunk, and limbs at any given moment. So this river is kept flowing, as you know, by a powerful force pump, the heart.

In a river that has no beginning or end, we might start at any point in the body to trace its course. For convenience and because of the color change which is here suggested in picture, we start at the heart. From the heart the blood flows through the arteries. In that part of the stream marked "Artery" you see it flowing along. On the surface float little red corpuscles, represented in the picture as manned by sailor lads. These red corpuscles are the carriers of oxygen which they are stopping to distribute all along the way. This is a fanciful picture. If it were true to life the river would be so crowded with corpuscles that you could see nothing else. They are so tiny that thirty-two hundred of them would have to be lined up in a row to stretch out to the length of an inch. That means that if you tried to imagine a solid inch of corpuscles, that is, a cube with three dimensions like a block of wood, you would have to multiply thirty-two hundred by thirty-two hundred and then by thirty-two hundred again for the number of these tiny objects that could be packed into it. That would get you into the realm of billions in a single cubic inch, and billions are beyond imagination. Red corpuscles are not the only ships that float on the river. There are white corpuscles, too, only in much lesser numbers.

THE CHANGE IN COLOR

The change in color in the river comes with the discharge of oxygen. When the red corpuscle gives up its oxygen, it loses its bright red

A RIVER THAT CHANGES FROM RED TO BLUE

THE NAVY

The river of the blood is swarming with life. A drop of blood, examined under the microscope, is found to contain more than five million corpuscles. It is said that the number of corpuscles floating on the river at any given moment is greater than the number of human beings who have lived on the earth since history began.

In the picture corpuscles are represented as ships. The life which keeps them at work, receiving and discharging their cargoes, keeps the body alive and healthy.

In the lung oxygen, which has been breathed in and "sprayed" on each tiny stream of blood, turns it back to red, the waste being left behind to be breathed out.

THE BLOOD THE RIVER OF LIFE

The river starts red from the heart through the arteries carrying, by means of billions of red corpuscles, oxygen and food to the extreme parts of the body. It returns blue through the veins, picking up cargoes of waste. The heart, receiving this blue stream, pumps it into the lungs, there to discharge its waste. From the lungs the blood returns to the heart ready to start again.

color. The blood returns through the veins purplish or even bluish in color, as you see it through the skin when you look at the veins on your hand or arm. As it returns it picks up waste materials and carries them along. In the upper left-hand part of the picture you see the blood as it looks when it is flowing through a vein.

The river changes from red to blue when it gives up its oxygen. It changes from blue to red again when it gets a new supply. If the circuit around which the blood flowed was only from the heart through the arteries and veins and back to the heart, there to start again, the blood would not be the river of life which it is. When it has been returned to the heart, it takes a turn through the lungs. There it discharges its waste, which is breathed out from the lungs into the air; there it receives a new supply of oxygen, which has been breathed into the lungs from the air. Red from its rich supply of oxygen, it flows back to the heart and is off again on its life-giving circuit through the body.

Such is the story which the artist has pictured graphically for us. The picture is fanciful. There are no such scenes actually going on within our bodies. But exactly the same operations are being performed through the magic stimulus of life. They are out of our sight and are difficult of observation, even under the microscope, by trained physiologists. The blood is truly a river; it serves in our bodies as common carrier for this precious freight. It is true to the spirit of truth if not to exact fact to picture it as if it were an ordinary out-of-doors river and the doughnut-shaped corpuscles as if they were manned by Lilliputian sailors. This picture with its story gives only the barest outline of the wonderful operations that are constantly taking place on this river. With the picture in mind, it will be interesting to go more into detail.

WHAT IS THE BLOOD MADE OF?

A drop of blood looked at under a microscope shows a liquid in which are floating a multitude of solid bodies. The liquid, called blood plasma, is a pale, colorless substance ninety per cent water and the remaining ten per cent made up of a variety of compounds which make the plasma a very complex substance. In no place in the world is the property of water as a solvent more valuable than in the human body. It dissolves minute quantities of important chemicals and carries them from place to place. In this plasma are suspended the red corpuscles, white corpuscles, and a third kind of corpuscle called blood plates or platelets.

THE OXYGEN CARRIERS

Red corpuscles are circular disks, slightly hollowed in the center and about four times as wide as they are thick. They are soft and jelly-like, readily pushed out of shape but springing back as soon as the pressure is removed. They are about sixty per cent water and forty per cent solids; of the solids by far the larger part is the coloring matter, hemoglobin. Its value in the blood is that it takes up oxygen easily, becoming by the process brighter in color, and gives it up as easily. In the last section we talked of the way in which molecules were built from atoms, and of the symbols which told, if you knew how to read them, whether a molecule were simple, like H_2O with its two parts hydrogen and one part oxygen, or complicated. Just to show you what kind of complicated substances life makes use of in its processes, let me tell you that one formula for hemoglobin is $C_{758}H_{1203}O_{218}N_{195}FeS_3$. That is, it has carbon, hydrogen, oxygen, nitrogen, iron (Fe), and sulphur in these proportions. A hemoglobin molecule has in all 2378 atoms, with an inclination to take on more oxygen.

You will remember in a much earlier chapter in the book the story of the carbon-oxygen cycle of life. (See page 46). Carbon, taken into the body in food, is held there awaiting a chance to reunite with oxygen. The red blood corpuscles make this union possible. There are billions of them moving rapidly through the body. A drop of blood the size of a large pinhead is said to contain more than five million red corpuscles. The number of corpuscles floating on the river at any moment is calculated to be greater than the number of human beings who have lived on the earth since history began. So rapidly does the river run that these red corpuscles are floated through the lungs every thirty seconds,

giving a chance for the taking in and distribution of a great amount of oxygen.

THE WHITE CORPUSCLES AND BLOOD PLATES

The white corpuscles have a very different rôle. They are larger than the red ones. In health there will, however, be only one white corpuscle to three or four or five hundred red ones. Red corpuscles float on the river of the blood with no separate activity of their own. It is even doubted whether they have at the time when they are serving as oxygen carriers any life of their own. They are made in the red marrow of the bones from a tissue which is located there. The cells of this tissue multiply, store up hemoglobin (a liquid) in their sacs, and are cast off into the blood stream, where they go round and round picking up and giving off oxygen. In time they seem to wear out and be cast off. They have no nucleus or living center like true cells. White corpuscles are real cells. Each one of them is as alive and as capable of changing its shape, taking substances into itself, managing its own locomotion so that it will go in the direction in which it wishes to go, as our old acquaintance the single-celled amœba. (See page 100.) They serve a very important purpose, of which we shall have more to say later, in keeping the body clean and in defending it. They are the street cleaners and the defenders of the body. They take microbes into themselves and eat them as the amœba takes in its food. They do not stay always in the blood but slip through its tube walls into other parts of the body, where they act as useful wandering cells.

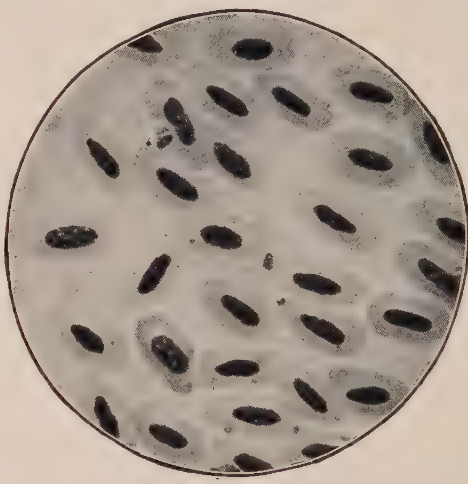


Photo by Philip O. Gravelle
BLOOD OF BIRD
(Magnified 1000 Diameters)

Photo by Philip O. Gravelle
BLOOD OF SALAMANDER
(Magnified 1000 Diameters)

The third kind of corpuscle, smaller than red corpuscles and discovered much later than the other two, is the blood plate or platelet. It is such a retiring member of society that although there are six hundred thousand or so in a single drop of blood, they will disintegrate (go to pieces) so fast when a drop of blood is drawn that before it can be looked at under the microscope, every one of the six hundred thousand will be gone. They serve some part in making blood clot, a service which is very important, as we shall see later, for it keeps the river of blood from running away rapidly through an open place in case of a cut or wound to the tubes in which the river is making its circuit.

In many animals the red corpuscles are much less numerous than in a man. Sir Ray Lankester is authority for the statement that in a drop of human blood there are a thousand times as many red corpuscles as in an equal-sized drop of frog's blood. To be sure, a frog's red corpuscles are larger, but in spite of that human blood is some hundred times richer in

hemoglobin than the frog's and so has a proportionately greater power of carrying oxygen from the lungs to the tissues. On the supply of oxygen depend both the warmth of the body and the possible activity of the body. So we human beings and others of the warm-blooded mammals are fortunate in our enormous supply of red corpuscles. The size of the corpuscles bears no relation to the size of the animal. The elephant and the humming bird, says Gravelle, have corpuscles of about the same size. Each of his three photographs shows blood magnified to the same degree, — one thousand diameters; yet how different the sizes of the corpuscles for human blood, the blood of the bird, and the blood of the salamander!

EXPLORING THE RIVER

Columbus set out to explore an ocean, Peary to reach the north pole, William Harvey set himself to explore the river of blood that flowed in his own veins and arteries, and his task was by no means the easiest of the three. He heard the labored explanations given by the medical teachers of the early seventeenth century of how the blood ran this way and that through the veins and arteries. One leading doctor taught that the stomach took in food, turned it into one kind of blood, and passed it on to the liver. In the liver it was mixed with "natural spirits" — whatever that might be — and from that moment was another kind of blood, "alive" and fit to nourish the body. From the liver it went to the heart, and the heart was a vat in which the "vital spirits" of life were brewed and mixed with the blood. From the heart this new mixture went out to all parts of the body. But what about these two sets of tubes that ran out from the heart, the veins and arteries? the students asked. That was very simple, the learned doctor replied; one set carried nourishing blood, that is blood from food, and the other set distributed blood which carried life and heat. Did not a body need food, life, and heat? Did not life and heat leave the body if the heart stopped beating? The heart furnished all three. So he got past that difficulty, or thought he did, but only to meet another. Why did the heart beat, and why could a pulse be felt at the wrist? The blood ebbed and flowed in the body, he replied, as the tide ebbed and flowed on a seabeach, a back-and-forth motion. That was Nature's way. We smile as we read the quaint, carefully worked out system; but which of us would have known better? To find out the workings of a tiny inner machine was no simple matter.

Young Harvey, unsatisfied, left the halls of learning where he had been so taught and set himself up in London as a practicing physician. But in all the time he could get he worked on this problem of what happened to the blood as it moved in the veins and the arteries. After

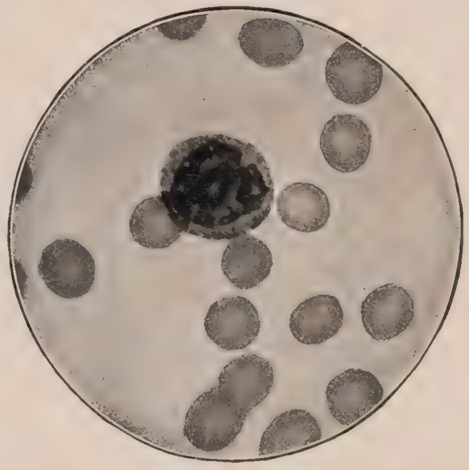


Photo by Philip O. Gravelle

HUMAN BLOOD
(Magnified 1000 Diameters)

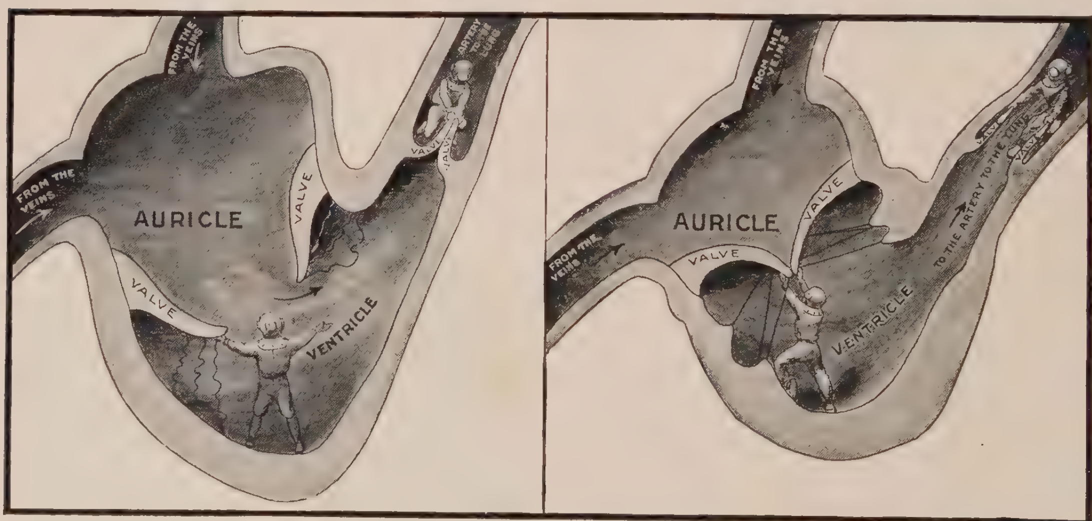
Showing red corpuscles and one white corpuscle (stained so as to be visible under the microscope).

fourteen years of patient, tireless investigation, he found out how the blood circulated and how the heart worked as a double pump. Besides his observations on the higher animals he had studied frogs and lizards, doves, oysters, tortoises, snails, crabs, slugs, shrimps, mussels, snakes, fishes, "even wasps and hornets and flies." In the year 1619 Harvey gave before the College of Physicians in London a set of lectures in which he showed how the heart worked, and declared that "it is absolutely necessary to conclude that the blood in the animal body is impelled in a circle and is in ceaseless motion." In such simple words was announced the truth of the circulation of the blood, which was to revolutionize medical knowledge. Columbus

discovered for Europe a new continent; Harvey, it has been well said, "gave the world of learning a new continent of knowledge." The learned doctors who listened shook their heads and said, "How can these things be? This is not as we have been taught from our youth up." After Harvey published his book, it was said that "he fell mightily in his practice, for it was believed by the vulgar that he was crackbrained." But before many years had passed he was made the king's physician, in token of the honor in which he was held. Let us see just what it was that Harvey suggested and that modern methods of observation have proved to be true.

THE HEART DOUBLE-CHAMBERED

The heart is a hollow organ about the size of a closed fist with walls of muscle and with a right chamber and a left, the two separated by a wall. Each chamber is, in turn, divided into two sections, an upper called the "auricle," a lower called the "ventricle." The auricle is the receiving section, the ventricle the pumping section. In the picture you can see them plainly, and see also how they are separated by a valve. The blood starts in the right auricle and flows, when the valve is open, into the right ventricle. The valve shuts with the heartbeat, and the blood flows from the right ventricle through another valve, which has opened at a second stage of the heartbeat, into the lungs. This is the process shown in the diagram. In the figure at the left it is flowing from the auricle into the ventricle; in the figure at the right the valve between the two has closed, but the valve toward the lung has been opened for the blood to flow into the lung. The course of the river of blood is, as you will remember, a double circuit. It goes from the heart to the lungs and back to the heart, then from the heart around the body and back.. That is why there must be two separate chambers in the heart. What is shown here is the right chamber, which receives it from the veins and sends it on to the lungs. The left-hand chamber is built on exactly the same pattern. A diagram of it would look like this one, except that instead of receiving blood from the veins it would be receiving it from the lungs; and from this chamber it would be discharging into the arteries, which carry blood over the body. From the arteries the blood flows out through capillaries, which branch out from the arteries as brooks branch from the main channel of a river or twigs from the trunk of a tree. From the capillaries it passes into veins which conduct it back to the heart, where it enters again the right chamber pictured in our



WHEN THE HEART BEATS

The right chamber of the heart in its two successive actions, first with the valve between the auricle and ventricle open, and the blood from the veins flowing freely in, and, second, with the valve between these two parts of the chamber closed but the valve opening toward the lung open to let the blood pass on.

diagram. There must always be the two parallel systems of arteries and veins running through the body, for the blood that goes by the arteries must be brought back through the veins. There must also be the double circuit for the main stream, for besides this trip around the body, it must pass on each round through the lungs.

KEEPING BLUE BLOOD AND RED BLOOD SEPARATE

Blue blood is impure; it has lost its oxygen and is loaded with waste matter. Red blood is pure. It is of the greatest importance in the condition of an animal that the two be kept apart. Birds have a double heart like our own, with two completely separate chambers, each in two sections. The valves work as they do in our own bodies so that the blood cannot run back from one section into the other. When one valve shuts, the other opens, but not until then. In the lower animals this is not usually the case. The heart begins as a long tube. Finally it becomes a closed tube, then the whole tube or a part of it contracts at regular intervals, driving the blood forward through it. Then a single heart with a single auricle and ventricle appears, and the separation of the two kinds of blood begins; but still they are mixed together in the heart. Finally, as we examine the higher forms of life, we find a double heart with its two chambers each with its own two sections separated by a valve. But the two chambers are not completely separated as they are in birds and mammals. The advantage of two separate chambers is this: If the impure blood can all be pumped through a chamber of the heart into the purifying region of the lungs, and no drop of it ever run back into the other circuit of the body until it has been made pure, the body will always have flowing from the heart through the arteries a fresh supply of pure, food-carrying, oxygen-bearing blood. But if the impure blood mixes in the heart with the pure blood received from the lungs, the blood stream will never be quite pure. In snakes, for instance, this condition can be observed. Half the effect of the lungs in purifying the blood is lost because back in the heart it comes in contact with the impure blood that is on its way to the lungs. Snakes are cold-blooded and low in the scale of activity or intelligence. This is partly because of the state of their blood stream, on which animals depend for supplies from the outer world.

In crocodiles we see very plainly what a difference it makes if there is even the slightest chance for red blood and blue to mix. The crocodile has two chambers in the heart, as do birds and mammals; but this does not save him, for where two arteries cross each other, as they run from the heart, there is a tiny hole — a small opening in the partition which allows the impure blood to leak into the stream of pure, red blood. "And so a crocodile," says Dr. Beebe, "is only a crocodile, although evolution has lifted his heart almost to a level with birds and the warm-blooded animals. If this tiny hole could become closed, and the two streams of blood be kept separate, the eyes of the crocodile would brighten, his activity increase many fold, and in fact his entire plane of life would be changed." By so slight a lack in his physical make-up, so great a change is made in the crocodile's life. To know such a fact makes us prize the more our own double hearts. We are always in danger of taking our blessings, physical and of other kinds, for granted. One value of approaching the study of our own bodily machinery through the realms of lower life is to make us appreciate what a difference one little perfect device may make in our lives. Let us be thankful for that solid partition which lies between the two chambers of the heart, so that no "bad" or impure blood can get through and harm the river of life that flows from the lungs.

THE PUMPING SYSTEM

The muscular heart is a double force pump. Any one of us has a fair idea of how an ordinary force pump works. It must have two parts,—first, a device for pressing upon liquid as it is held in a chamber, and, second, valves in that chamber so arranged that the liquid can pass out, and must pass out, in one direction only. In the diagram of the chambers of the heart we saw the valves. The device for pressing upon the liquid is the "engine" in the wall of the pumping chamber. The left ventricle is the controlling pump of the heart. It is

larger and stronger than the right ventricle, though both serve as pumping chambers. It is wonderful that instead of building a separate engine somewhere near the pumping chamber, Nature has arranged that the entire wall of the chamber moving inward shall drive the blood out of the chamber through the outlet valve into the main artery, the aorta, from which it is distributed over the body. "The thickness of the wall of the left ventricle," writes Keith, who has made a special study of "The Engines of the Human Body," "represents a muscular engine, one made up of countless microscopic cylinders of a rather peculiar kind." The total weight of this engine, he continues, is just under a quarter of a pound in a person weighing 110 pounds. The wall is about half an inch thick. "The problem of grouping tens of thousands of contractile cylinders in the wall of a pump, so that each of them can exert its full power in forcing the blood from the pump chamber, taxed the ingenuity of Nature to its utmost." Take a rubber ball filled with water and try to empty it by compressing it with the fingers. The fingers will represent the compressing engine. It will be impossible to squeeze it with a uniform pressure on all sides at once. Nature does it by arranging layers of muscular cylinders in overlapping spirals, which do bring the walls uniformly inward until practically all the blood is driven out through the valve. "Thus the left ventricle is a very remarkable kind of pump — one with walls built out of the engine which actually sets it in motion, and in this way drives the blood onward."

The heart is the source of pressure of the pumping system. The aorta and other large arteries are like reservoirs where the main body of the stream is held, as, for instance, in a commercial water system it is held above a dam. All through the arteries and veins there are valves and stopcocks to check and regulate the flow.

A TWO HUNDRED AND FORTY HORSE-POWER ENGINE

The human heart beats at a very rapid rate. A whole beat takes less than a second of time; that is, if the rate of the heartbeat, as it can be counted by the pulse at the wrist, is the normal seventy-two beats a minute, the heart is going through this entire act of opening and closing its valves and pumping the blood through it seventy-two times in each minute. The amount of work done by the heart, as it keeps steadily at this pumping minute after minute and hour after hour during a twenty-four hour day, is amazing. To estimate work done, there must be a comparison with the usual standard measures of work. "When the heart is beating at the rate of seventy per minute," says Martin, "it does one hundred and forty foot pounds per minute, making it a two hundred and forty horse-power engine. If it maintained this rate throughout the entire twenty-four hours of the day, it would do in that time two hundred thousand foot pounds of work, an amount equivalent to that done by the leg muscles of a man weighing one hundred and fifty pounds in climbing a mountain thirteen hundred feet high." Or, to put it in another way, the work done by this powerful little muscle, not larger than one's fist, would be equal to lifting ninety tons to a height of three feet. Consider the bulk of ten tons of coal as it lies in your bins, and think what it would be to lift ninety tons three feet or ten tons twenty-seven feet.

HOW FAST DOES THE BLOOD FLOW?

With the heart pumping at this rate it has been found by experiment that the river dashes around its whole course once in every thirty seconds. Each red blood corpuscle is, therefore, swept through the lungs at least twice a minute. This gives a chance for a constant purifying and reloading of the blood with oxygen, so that it becomes in truth a life-giving stream.

AN EIGHT-HOUR DAY

Yet with all its rapid pumping, the heart does not under normal condition actually work more than an eight-hour day. This is because, though it works at such tremendous pressure while it works, it rests completely in the intervals between pumping. Between each two heartbeats it "recovers" from the effects of its activities, and it rests each time a little longer than it works. During sleep the heartbeat is at a

much slower rate than in the waking hours; so the eight or nine or ten hours of sleep help to bring the average down to that of an eight-hour day.

The work done by the heart is not done at an even rate every moment of the day. It depends on the activity of the body. When the body is in action its muscular engines require more fuel and oxygen than when they are at rest; for then they depend on the river of blood, which is their common carrier. So the heart must pump at a greater rate. Suppose, as has been calculated, that when a man is sitting quietly, the left ventricle or pumping chamber is throwing five pints of blood into the aorta, or main artery, every sixty seconds. If he gets up and starts to walk at the rate of four miles an hour, the output of blood will become four times as much. If he runs upstairs, it will be seven times as much.

The question instantly arises in one's mind, How does the heart know that the muscles of the body need this extra supply? Or, again, What keeps the heart beating at even an average rate? The action of the heart is connected with the nervous system. The heartbeat is not under the direct control of the will, as is the movement of the hand or the arm. We cannot make the heart stop or start at will. But though the impulse which keeps it going seems to be in the walls that surround it, the heart is also closely connected with the lower nervous system by which many of the body processes are regulated. In some way the lower nervous system sends messages to the heart as to conditions all over the body and the heart slows down or speeds up accordingly.

Nature has also planned that the work of the heart shall not be wasted. All over the body there is the most elaborate system of checks and stopcocks which work automatically to distribute the blood supply to the points where it is most needed at any particular moment. Every one knows how hard it is to do brain work immediately after a meal. The blood is being sent to the stomach and other organs of digestion, which are for the time being loaded with work. "Every time we alter our posture — when we lie down, stand up, or sit upright — there is a silent and automatic switching of the tens of thousands of vascular stopcocks of the body. We are so unconscious of this silent activity that we find it difficult to believe that it actually occurs." Every muscle or organ can somehow command to some degree its blood supply according to its needs. A healthy heart always responds to our bodily needs, whether we walk, run, dig in the ground, study, dance, or sleep. It is without exception the most wonderful pumping station in the world.

HOW FAR DOES A DROP OF BLOOD TRAVEL IN A DAY?

A man can find out how far he walks in a day by attaching a device which checks up every step he takes and the distance covered. If a similar instrument could be attached to a drop of blood, how far would it be found to have traveled? The distance varies according to the arteries and veins through which this particular drop of blood might travel. In the human body there are short cuts and short circuits from artery to vein and back again to the heart. It has been figured out that on the average any drop of blood will go nearly a mile a day. The length of this trip varies with the amount of time the blood spends in the capillaries. They are the fine channels connecting arteries with veins, which branch into all parts of the body. There is hardly a place where a drop of blood will not appear if the skin is pricked by a pin. They are literally innumerable. It is said that the capillaries in the lung alone are enough to reach across the Atlantic. They must run everywhere, for it is through the walls of the capillaries that the food and oxygen supplies "leak" through from the river of blood into the surrounding tissues of the body, through them that the waste material "leaks" into the blood, and lastly through those in the lungs that the oxygen "leaks" into the blood and purifies it. As the stream dashes rapidly through the lungs it must be so distributed that it can be reached by a great amount of oxygen. Capillaries are like the small pipes in our houses by which water is distributed from the great water mains in the street. "They are so narrow that the microscopic red blood corpuscles, each carrying its load of oxygen, can pass along only in single file." The network of capillaries is the essential part of the system by which blood is distributed.

COUNTING THE PULSE OF A BIRD

The heart of a bird is built on the same pattern as that of a man; but in a tiny bird so powerful a pumping station seems even more remarkable. In the first place, the heart is very large in proportion to the size of the bird. Also, the heart of a bird beats very fast. A man's heartbeat is at the rate of about seventy pulsations a minute. If it runs much higher for any length of time, a physician is called and the man is put to bed and given treatment which will slow down the heart action to normal. If you could count the pulse of a bird, you would find the heartbeat about one hundred and twenty times a minute when the bird is at rest. "The first flap of the wings doubles the pulsations, and when the bird is frightened or exhausted the number of beats are too many to be counted."

The blood stream of a bird, as that of a man, does more than supply food and oxygen to all parts of the body. It keeps the temperature of the warm-blooded animals even. As the bird has a higher pulse than a man, so also it runs a much higher temperature. A man would be in a high fever if he ran anywhere near the temperature that is normal for a bird. This explains in part the bird's ability to make the long flights at which we have marveled in earlier chapters.

So brief a story does not end the tale of the wonderful river of life, the blood. We shall come upon it again and again in the stories of "The Breath of Life," by means of which the blood receives its oxygen; of temperature and life, telling how the heat-regulating system of the blood makes it possible for man to live "from Greenland's icy mountains" to "India's coral strand" instead of crawling into a warm den and hibernating at the approach of cold, or panting away his life when the thermometer rises, and of food and life, showing how the blood supplies the fuel which keeps the engines of life going. Truly this is, as Lankester says, "the rarest, most precious, most gorgeous of fluids."

BLOOD AND SEA WATER

Of the materials which life uses, and of the wonderful unity which runs through the living creation.

ONCE in a while we come upon a fact that brings out very clearly the unity of all living things. Such a fact is the amazing similarity between blood and sea water. When a man has lost a large quantity of blood through an accident, the doctor injects into his veins a salt solution which is very like sea water in composition. From this the body will soon make blood which will take the place of that which has been lost. As life is thought to have started in the sea, it becomes interesting to begin with the simplest creatures and see whether their blood is more or less like sea water than that of man.

WHEN "BLOOD" IS SEA WATER

Blood is the common carrier, the circulating medium which travels through the body delivering food and oxygen and carrying off waste. If we begin as far down the ladder of life* as sponges, we find that they have no need of blood. Most of their cells get their own food direct from the sea water; for those which are inside and cannot, it is passed to them through their cell walls. Next up the scale come corals, sea anemone, and jellyfish. These animals have barrel-shaped bodies. The hollow part within behaves exactly like a huge blood vessel in carrying food and oxygen to the inner parts of the body. But what is the "blood" of this hollow tube? It is sea water itself. The body is directly open all the time to the sea water in which the creature dwells. The sea water flows in at the mouth with the food; it acquires, on its way through the body, digestion ferments which improve it for its purpose; it picks up, as it passes along, waste

* See Volume I, pages 212–213.

products, which it carries off out of the body. In short, the blood is formed from sea water flowing through the body, and accomplishes in a simple way for this simple creature just what true blood does for the higher animal.

As we go up the ladder of life, studying the sea creatures, we find the digestive tube becoming closed, and blood vessels appearing, but still the basis of the blood is sea water. This kind of liquid seems to have worked so well that it is repeated here. In the shellfish there is a heart with arteries and veins, and here there is a change. The blood is colored! In some species the corpuscles have hemoglobin, the substance that makes man's blood red; in others, another similar substance, hemocyanin, which is blue instead of red but which has the same power of taking up oxygen, transporting it, and giving it off. These creatures, then, have blue blood which serves them as well as our red blood serves us.

If many sea creatures manufacture, so to speak, their own blood from the water in the midst of which they live and the food which comes to them in this water, and it proves to be a satisfactory river of life for them, it is not surprising that the blood of the higher animals and man should be very like sea water in its composition.

BLOOD AND IRON

When we speak of a man who shows physical vigor and courage, we sometimes say that he "has good red blood in his veins." Again, if a man shows great powers of endurance and grim determination, the saying is that he "has iron in his blood." Both of these figures of speech are true physiologically. A man's strength depends on the red in his blood, the millions of corpuscles with their hemoglobin coloring matter which make blood an oxygen carrier. And the hemoglobin depends for its redness on the least bit of iron that is in it. In the formula for hemoglobin there was only one part iron in a total of 2378 parts. Yet that iron gives it, so they tell us, its red color. In the blue-blooded shell creatures of which we have spoken hemocyanin takes the place of hemoglobin, copper takes the place of iron in the compound. Iron has a great tendency to combine with oxygen, as we know from the way iron exposed to the air becomes coated with a reddish rust. Copper, too, unites easily with oxygen. So either will serve as oxygen carriers.

The iron which is found in such small proportion in the blood is the only iron in the body. In all the other organic compounds of which the body is made up, there is not even so tiny a portion of iron. Yet this iron, one atom in 2378, gives the blood its color. As Ruskin has poetically expressed it, "Is it not strange to find this stern and strong metal mingled so delicately in our human life that we cannot even blush without its help?"

THE RED AND THE GREEN

An earlier chapter told of color and its part in the patterns of life's coverings. Here it is interesting to think about color again, this time of the part coloring matter plays in the scheme of our own lives. The green coloring matter of plants, chlorophyll, makes possible the life of the plant world, without which there could be no human life. This green coloring matter enables the plant to take carbon from carbon dioxide and to set free oxygen. The oxygen goes back into the air. There it remains until it is breathed into the lungs. In the lungs another coloring matter, this time the red hemoglobin, picks up this same oxygen and carries it around the body until it finds its carbon. Red and green — both are most significant in our lives. To our story, "At the Sign of the Green Leaf," we have added one which might have been entitled, "At the Sign of the Red Corpuscle." Without the color in Nature it would appear that there would be no life.

THE BREATH OF LIFE

Of life as it depends on air, of the marvelous device of lungs which hold a gallon of air, of breath and voice.

WHEN man was formed from the dust of the ground, there was breathed into his nostrils the breath of life. It is a beautiful picture of man's dependence not only on God for the gift of life but also on the world in which God has placed him for the continuance of that life. A man's body may be the most perfect of machines, but before the spirit of man can dwell in it — before man can "become a living soul" — he must have breathed into his nostrils the breath of life. If the breath should never come into the body, the human machine would stand idle. When the breath goes out of the body, the life goes out with it.

FREE AIR

In front of a garage one will often see a sign "Free Air." The automobilist knows that he can have air to fill his tires for the pumping of it, and that the pump is there provided. Man is put down in a world of free air, and the pumping system is provided within the chest. He needs only to take in the air through the nostrils by the act of breathing; the machinery is already at work which will do the pumping. In the lungs the air will be brought into contact with the swift-flowing blood stream which seeks from it life-giving oxygen and delivers to it a load of waste materials.

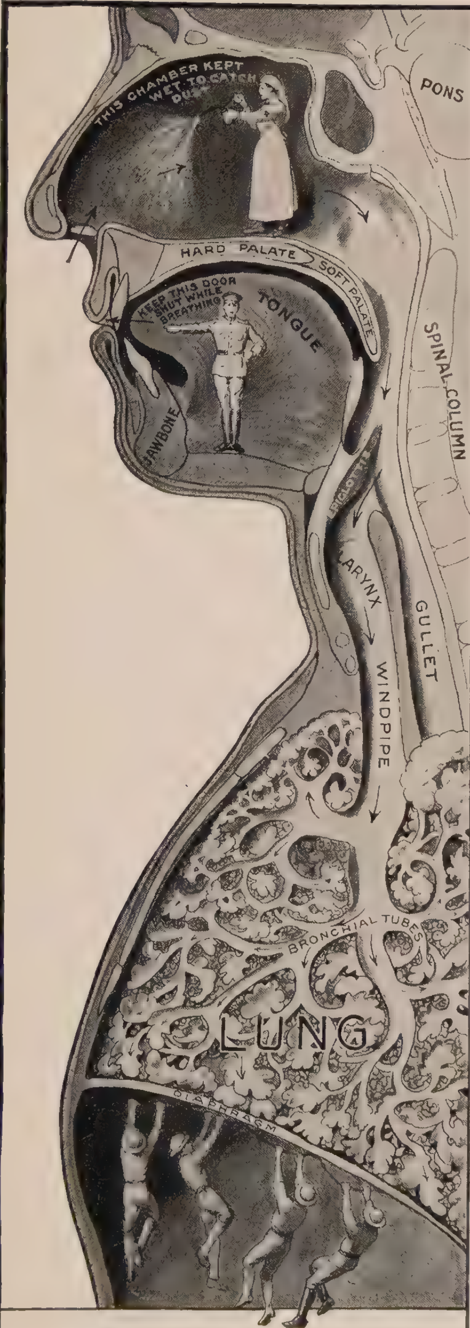
HOW THE BODY IS PROTECTED

The pictorial diagram on the opposite page presents in a graphic way the method by which air is taken into the body. The inner part of all our bodily machinery is very carefully protected; it never comes into direct touch with the outer world. Nor are its supplies delivered to it in exactly the raw state in which they arrive at the outer door. They are carefully prepared before they are allowed to reach the delicate inner machines. The lungs are to receive air and deliver its oxygen to the blood. But the lungs are not on the surface of the human body, as the gills of a fish are on the surface of its body. The approach to them is guarded by a set of passageways through which the air must pass. The nose is the entrance for the air; it is the guardian for the lungs. As the mouth protects the stomach, so that nothing improper shall get through to it, so the nose is provided with devices for the straining, warming, moistening, and purifying of the air which is on its way to the lungs. The actual mechanism by which air is moistened and dust is filtered out of it is fully as effective if not so picturesque as the work of the brisk little Red Cross nurse in the picture.

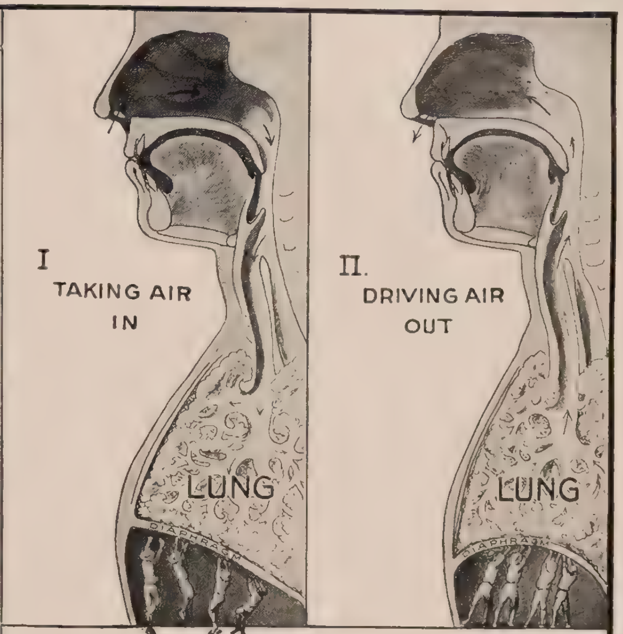
THE NOSE THE GUARDIAN OF THE LUNGS

If the air tube were straight and open, air with dust and germs in it might drive right through to the lungs. But the nasal chambers are not open and direct tubes. The airway winds in and out through curious curving scrolls of bones which are covered with skin that is always kept moist. Particles of dust and germs get caught in the winding paths and stick to the skin as flies stick to fly paper. The skin, or "mucous membrane" as it is called, has little hairs coming out from each cell which act as brooms, constantly moving back and forth and sweeping impurities back from the inner tubes. Another job is attended to in the nose. The scrolls of skin are kept hot and moist by the blood which is coursing through them. They give the air moisture and they give it heat. As it travels around in the crooked passageways it is warmed as if it were passing over hot radiators. If you are breathing through your nose, you need have no fear in zero weather that the freezing air will strike a chill into your lungs, for by the

HOW WE BREATHE

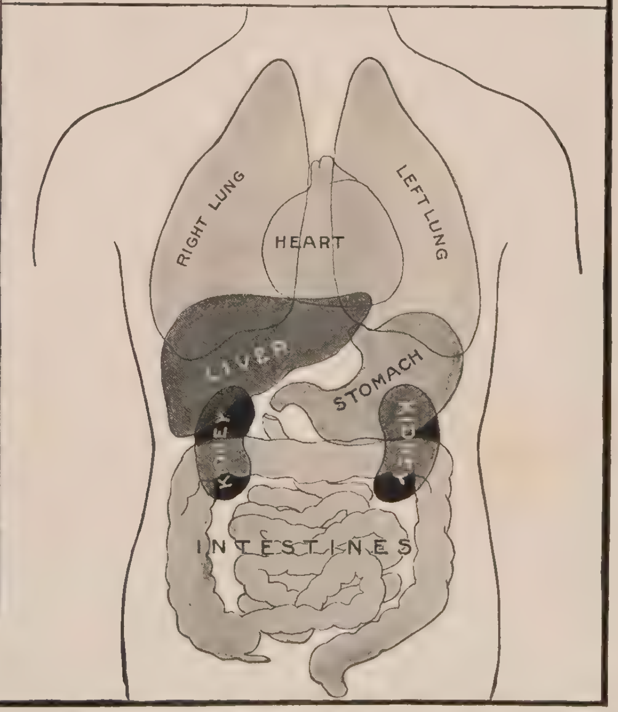


AIR TRAVELING THROUGH THE NOSE AND DOWN TO THE LUNGS



PULLING DOWN THE DIAPHRAGM

PUSHING UP THE DIAPHRAGM



THE PROCESS OF BREATHING

THE POSITION OF THE VITAL ORGANS

Air is taken in through the nose, cleansed of dust, warmed, and sent down the winding way to the lungs. When the muscle that runs across the lungs called the diaphragm is pulled down, it lets the lungs expand and take in air. Then in a second or so it pushes up again, narrowing the space for the lungs and so squeezing out air. Make yourself take the place of the little men of the picture-story and see to it that you breathe deep and fill your lungs full each time.

time it gets through to the lungs it will not be freezing air. The colder the air breathed into the nose, the greater is the flow of blood through the radiators. Air entering the nose with a temperature just below freezing (32° F.) has been tested and found to be warmed to summer heat (81° F.) before it ever reached the lungs.

DO NOT BREATHE THROUGH THE MOUTH LIKE A FISH

But if you should have the bad habit of breathing through your mouth, then the nose can perform none of these good offices for the protection of your lungs. The artist can place a sentinel at the entrance of the mouth in the picture, to enforce the order that this door is to be kept shut while a person is breathing. But you are the only person who can put such a guard upon your mouth. Only by firmly resolving not to breathe through the mouth and by seeing to it that the message sent from your brain is obeyed, can you protect your lungs from the bad effects of this careless opening of the wrong door. The mouth is for food; it can be opened and shut, for food is taken only at intervals during the day. The nose is for air, which must enter at all times of the day and night; it is always open, and always guarded. If you were a fish it would be proper for you to breathe through the mouth, for that is the way fishes are made; but being a human being with both a mouth and a nose, you should breathe after the manner of human beings, not after the manner of fishes.

AN IMPORTANT GATEWAY

From the nose the course of the air takes a sharp turn, down back of the soft palate into the throat or pharynx. This is the wide-open channel into which the mouth opens as well. You can see very plainly in the picture how the throat divides into the gullet, which is the food tube, and the windpipe, which is the air tube. At the entrance to the windpipe is a lid or gate called the "epiglottis," which shuts down when food is passing through the gullet but stays open the rest of the time to let air pass through into the windpipe. This is one of the most important gateways in the body. Once in a while it fails to work, and then you realize how important it is. When you start to laugh and at the same moment are trying to swallow, this little gate gets from the brain two sets of orders, — one to stay shut for food that is passing down the throat, one to stay open to give breath for laughing. It cannot be open and shut at the same time. Between its attempt to do two things at one and the same instant, a bit of food may slip into the upper tube of the windpipe. You will know of this because you choke. Choking is Nature's effort to drive the food back from the windpipe where it has slipped in by mistake. As soon as the food gets back on its proper course, all will be well again.

ENTERING THE LUNGS

At the upper end of the windpipe is the larynx, where voice is produced. In the soft folds of the walls of the windpipe lie the vocal cords. Of these we shall speak later. Now we are interested in the passage of our current of air to the lungs. It travels down the windpipe until the windpipe branches into the bronchial tubes. Here again are hairs or cilia to sweep the air clean. In his book, "The Engines of the Human Body," Dr. Arthur Keith has given so perfect a description of the work of these hairs that I am going to quote it for your pleasure as well as your information.

"Chimneys lined with automatic sweeps have not yet been thought of," he writes, "but a contrivance of this kind has been adopted by Nature for keeping clear and clean the airways to the respiratory chambers. Conceive a chimney set with boot brushes, so that their hairs or bristles form a continuous lining on which the soot from the smoke is constantly falling, and conceive, too, that the bristles are in constant movement, waving every particle of soot which falls on them in one direction, — namely, from fireplace to the vent, — then you have some idea of the contrivance which Nature has adopted to keep the breath passages clear. The bristles or cilia which line the air passages are so delicate that they require a strong microscope to bring them within the range of our vision; the backs in which the ciliary brushes are set and which keep the

bristles in motion are microscopic brick-like corpuscles with which the air passages are paved. Cilia cannot work unless they are kept moist; hence everywhere along the walls of the respiratory passages we meet with the mouths of small glands or workshops at which a clear, sticky substance called 'mucus' is being constantly thrown out to meet the needs of the cilia."

IN THE LUNGS

As the windpipe enters the chest it divides into the bronchial tubes. These divide again and again into the air sacs, which look in the picture, as they actually look in the human body, like the down-hanging leaves of a branching tree. The air chambers or sacs hang in clusters. Each air chamber is little more than a single layer of cells and a little tissue connecting them. The walls are very thin and delicate, and are elastic, so that they stretch to take in air and shrink when it is let out. Each is about one-tenth of an inch long and one-thirtieth of an inch wide. There are said to be six millions of them in the two lungs. These are the tiny chambers that fill with air when the breath is taken in. Around them run the network of capillaries which carry the blood stream from the heart. The walls of the tiny air chambers are so thin and the walls of the capillaries are so thin that it is the simplest thing in the world for the oxygen to pass through from the air chamber to unite with the hemoglobin in the blood, and the waste (carbon dioxide) from the blood to slip over into the air chamber, from which it will be breathed out through the bronchial tubes, the windpipe, and the nostrils.

A GALLON OF AIR — A GALLON AND A HALF OF BLOOD

The way to get any sense of the cleverness of Nature's mechanical devices is to consider the problem which had to be met. A riddle looks easy — after it is solved; an example in arithmetic is simple — after it has been worked out. Speaking in rough numbers there is in the human body about a gallon and a half of blood. This blood has to go through the process of being aërated, that is, of having the oxygen from the air driven over it so that the red corpuscles can pick it up. There is in the lungs, speaking roughly, about a gallon of air; the biggest breath a man takes will drive about that amount into the lungs. It is Nature's problem to bring, within the small space allowed for the purpose in the chest and between the ribs, a gallon and a half or so of blood into relation with a gallon or so of air. The way this is done in the smallest space possible is one of the greatest marvels of the body machinery.

If the lungs were an open balloon, they would be about ten feet in diameter. That is hard to believe. Let us see how that statement can be made. There are within the chest walls about six million air sacs, which with the air tubes make up the area of the lungs. It has been calculated that if the lining of each air sac were spread out flat and the whole number of tiny pieces, six million in all, were put together in one big balloon skin, that piece of skin would make a balloon ten feet in diameter. Put it in another way. Those same pieces of skin laid on a floor with no space between would cover the floor of a room thirty feet square. Put it in still another way. The membrane which lines the lungs of a man of average size is supposed to have an area one hundred times that of the skin which covers the body. All of which is to say that into the lungs is packed, by the scheme of tiny air sacs closely fitted together, an enormous, unbelievable area of skin surface. On one side of this tremendous area of thin skin, as it is distributed in six million tiny air sacs, lies air. Every air sac is not filled at every breath. Far from it! But a great many air sacs are filled, emptied, and refilled in the act of breathing, and others get the air passed on to them. On the outside of this skin area, that is, on the outside of each sac, run capillaries, or fine tubes, containing blood. No wonder there are billions of red corpuscles in the blood stream. There must be for them to pass in single file through this huge network of capillaries. Every single inch of the great lung surface must have poured past it thousands of red corpuscles which will pick up the oxygen on the other side of the wall.

A gallon of air pressing on one side, and a gallon and a half or so of blood rushing through on the other side of the skin wall — it is the

prettiest device for aërating the blood that could be devised, and the greatest marvel of all is that by putting the skin wall into multitudes of the tiniest of air sacs and running the blood over these sacs in tiny winding tubes, the whole process can be managed in a space no bigger than that allowed for the lungs within the chest wall. Each corpuscle gets around to the lungs at least twice a minute; the lungs take in air some fifteen to eighteen times a minute in normal, unhurried breathing, much oftener in rapid breathing, with the result of a fairly complete aëration of the blood once or twice each minute.

KEEPING THE AIR MOVING

The mechanics of breathing are partially indicated on the diagram. For practical purposes this is all we need to know of the method of filling and refilling the air sacs. Below the lungs runs the great muscle wall of the diaphragm, which moves up and down in the manner indicated. The lungs are never entirely emptied, seldom even partially emptied. If a person is sitting still, he takes in and drives out about a pint of air with each breath. This amount is sometimes called the "tidal air." It ebbs and flows like the tide. Then there is the possibility of taking in about five times as much when a deep breath is taken, or when some activity like running upstairs, chopping wood, or taking any form of violent exercise calls on the lungs to pump their bellows faster and deeper. Beyond this lie the reserves of air which may be used in times of great stress, and there is always remaining in the deep places of the lungs some air which is not expelled. The purpose of deep breathing is to keep the air moving through as much of the lungs as is natural. Exercise is good because it calls parts of the lungs into use which are not otherwise kept so active and healthy. Back of all in the well-developed body lies the safe reserve of lung capacity which will tide us over the accidents, illnesses, and emergencies of life.

IN COMPARISON

All through the book it has been our thought that we appreciate our own possessions more if we compare them with those of others. We know that every creature, however humble, must breathe. From our own comfortable vantage point as lung breathers, we turn for a moment to a consideration of what the lower creatures have in the way of breathing apparatus.

BREATHING UNDER WATER

It would seem as if it would be a far simpler matter to breathe in the air than in the water. As a matter of fact water creatures get their supply of oxygen from the air caught between the molecules of water with far less elaborate apparatus than is required for air dwellers. The reason for this is that if oxygen is to pass through a skin wall, that wall must be kept moist. This is obviously simple for a creature that lives in water. His breathing machinery can be on the surface of his skin — all over his skin if that is desirable. When something more elaborate is required, folds of surface skin can be developed into special breathing organs. This is what happens with fishes. They take water in through the mouth. When it gets into the throat it is forced away from the food tube or gullet through a series of openings, so that it passes over the gills and out from the body. The gills lie in layers of thin membrane, as you see in the photograph, and contain hundreds of blood vessels which take up the oxygen from the current of water which flows over them. It is the same principle as that on which lungs are built, only the mechanical device can be much simpler.

AIR TUBES AND LUNGS

Insects need a great deal of air, or rather of oxygen, in proportion to their size. They live in the air, and therefore cannot keep a moist surface on the outside of the body through which oxygen may pass into the cells within. So they have tubes that open into the air and then divide in a very delicate piping system which runs all over the body, distributing oxygen to each cell. These tubes may lie wholly within the body and open anywhere on the body surface, or they may be projected out in separate structures like a length of rubber hose.

When we examine the higher animals, we find that for them as for man it has been more convenient to have lungs. These lungs may be very simple sacs, not divided or subdivided as in the human body. But they are packed away safely within the body, where they may be kept moist. The blood stream is run over them in the same way. And in general the tube by which air enters the lungs is connected with the food canal. Since there must be a canal by which food is to enter, it is in accordance with Nature's policy of economy of space and machinery to have that same tube used for air. In many of the higher animals, as in man, there is another doubling up; the nose, the organ of smell, is used for the air entrance, containing besides its olfactory end-organs the chambers where air is warmed and purified. It is so natural for us to have the nose used for both breathing and smelling that we do not pause to think what a clever arrangement it is. The story of this double use is fully told in the chapter on "Our Servant Smell."

BREATH AND VOICE

We are indebted to the breath of life for another service. Without breath there could be no voice, no song, no speech. Nature has done another bit of doubling up. Instead of having a separate voice box with a separate current of air and separate machinery to run it, Nature has placed the larynx, or voice box, right in the path of the incoming and outgoing currents of air sent to the lungs. At the head of the windpipe you will see in the diagram the word "larynx." The act of breathing keeps the air passing through this muscular box. Within it lie the vocal cords, soft folds of skin, bands of elastic tissue. They form a gateway to the windpipe. When they are wide open the air rushes through and no sound is produced. When they come closer together the blast of air sets their edges shaking or vibrating, and sounds result after the same fashion that sounds come when a boy blows on a blade of grass held between his thumbs. All the varying

Photo by R. W. Shufeldt

RAINBOW TROUT WITH SKIN FOLDED BACK TO SHOW GILLS FOR BREATHING

sounds of the human voice start in the little voice box of the throat and depend on the control of the vocal cords and of the current of air which is flowing in and out to supply oxygen to the blood. By another economy the walls of the mouth and the tongue shape the outgoing air current into speech.

A BIRD AND A MAN

It is interesting to make a comparison concerning the use of breath for voice with birds, the singers of the world. A bird does something which we could not do. It sings and flies at the same time. "Even more wonderful than mere flight," writes Dr. Beebe, "is the performance of a bird when it springs from the ground, and goes circling upward higher and higher on rapidly beating wings, all the while pouring forth a continuous series of musical notes, the strength of the utterance of which is attested by their distinctness in our ears after the bird has passed beyond the range of vision. A human singer is compelled to put forth all his energy in his vocal efforts, and if, while singing, he should start on a run even on level ground, he would become exhausted at once." The reason for this lies in the bird's anatomy. A bird has more air in its body in proportion to its size than any other creature. Besides its windpipe, which is long, and its lungs, it has a system of air sacs connected with the lungs and extending all over the body. A bird is literally, as Dr. Beebe has said, a creature "of the air." There are many gains for bird life from this arrangement. Not the least is that the lungs are thoroughly used all the time. Birds breathe from twenty to sixty times a minute. The lungs of a bird may be small, but every part is used. A man uses only part of his lungs. Unless he keeps himself in good physical training and sees to it that he breathes deep, he wastes a large part of his lung capacity. The bird uses every bit of lung that it has, and has a reserve air capacity in the sacs upon which to draw. No wonder it performs the miracles of song and flight which it does! But a man can make much more use of his own wonderful lungs, which are big enough to make up for any extra air sacs which the bird has, if only he will take pains to fill his lungs as full as he can a dozen times a day. In this way he will get them accustomed to being fairly well filled so that they fill of themselves in the ordinary course of breathing. It is a shame to have such a wonderful pair of lungs in the body and let them get inactive through disuse. When we see what a necessary and wonderful process breathing is, and how we depend on it for the upkeep of the blood and cells, we shall wish to give the lungs all the air they need or will take. To keep a large amount of dead or partly dead air in the lower parts of the lungs because we are too lazy or forgetful to take a set of long breaths and drive it out for a new supply, is sheer wastefulness of our wonderful bodily machinery.

Photo by L. W. Brownell

THE BODY IN ACTION

Of the body as a community in which each group has its own tasks and all work together for the good of the whole.

A WHILE ago we talked about a beehive. We saw how each bee worked for the good of the whole. One kind of bee did one thing over and over and over again because that was what was needed in the hive. Another bee did another kind of service. Together they made a most successful working community. A human body in health is like that. It is the most harmonious and well-ordered working community in the world. That is why it can accomplish so much. Its workers are the single living cells. Alone each one could accomplish but little. Working together in groups they can play a most useful part in the life of the whole. One group does one kind of work; another group tackles another job which must be done. Together they put up a fight against any enemy which threatens the comfort or safety of the whole.

The way to appreciate such a community is to see it at work. To go through a factory when all the workmen are busy about their tasks is far more interesting and informing than to go through it on a Saturday afternoon when the machines are standing idle. We are considering in this section of the volume "The Machinery of Our Bodies." But here as elsewhere our interest is in life as it makes use of this marvelous and intricate machinery. It would be interesting to study each group of machines. But the human body as it is in action is so much more than a group of machines that even with the most careful and detailed study of separate parts we should miss its chief and crowning marvel did not we see it at work. Then each part fits into each other part, directing, modifying, balancing in a way that is the increasing wonder of students. If one part is overstrained and fails a little in its performance, some other part comes to the rescue with an adjustment that makes for the balance of the whole. The chemical laboratories work a little overtime, or headquarters summons reinforcements, or fatigue poisons are thrown off more rapidly; the breathing is hurried up, or the heart slowed down, or the perspiration increases. Somehow, if it be possible, the life in the body makes for the successful working of the community as a whole as well as the most efficient possible operation of each machine or group of machines.

So, to get a sense of life which we should otherwise miss, we are going to watch the community as it works at some of its most familiar tasks. We shall watch a piece of food as it enters the body and proceeds until it gives nourishment to the hungry cells which need it. We shall see what happens in the case of emergencies, — when you cut your finger, or when you have a cold. We shall examine in a superficial way the intricate and quickly responsive heating system of the community. And lastly, we shall visit headquarters and see how a series of daily activities is handled there. Each of these will be a story in itself, but each will be an illustration of the body as a great busy, thriving community. We shall stop and examine parts of the machinery as we go, but we are visiting the community at a time when it is hard at work. In this way, while we admire the intricate machinery, we shall not lose our sense of the life that is dominating and operating it. A mere machine is always the same. It repeats one operation over and over in a purely mechanical way. It does not change or adapt itself. The machinery of our bodies is more than mere machinery because of the life working through it, which makes even the working parts change and adjust themselves as is best for the common life of the whole. The machines of our bodies would be interesting if each were doing its work separately; but the fascination and the marvel of their operation come in the way they work together.

A FOOD JOURNEY

Following a piece of food to its destination in the body.

WHEN you take a man or a group of men out from their ordinary lives and set them at some special work, you have to feed them. So long as they are single individuals, it is their business to get their own food for themselves. But when they are set at work for the community, they have to be fed by the community. This is true of a jury. When the city or county or state asks or orders "twelve good men and true" to step out from the ranks of citizens and hear and judge the cases which have come into its courts, it must at once provide for having their meals served to them. In the same way the government must provide for its soldiers as they are held in camp on special duty for the country. The same need holds in the great organization of the human body. So long as a single cell floats about in the water on its own business, as does the one-celled amœba, it is its business to find food for itself. But when great groups of cells are massed for special duties, as they are in the body, there must be provision for feeding them. The soldiers are only a part of any army; there are hundreds of persons who will never reach the fighting line but who are concerned to keep the soldiers fed so that they will be free to go about the business of soldiering. Within the body there is an elaborate chain of food factories and a vast corps of workers which have to do with this one department of service.

If food when it went in at the mouth was in a form which each little cell member of the community could eat, all that would be needed would be a transport system by which food could be distributed. We have seen one section of that transport system in the blood. But there is not a particle of food which ever reaches a cell in the form in which it enters the mouth. Food as it enters the body is like raw material as it enters a factory. It must be worked over before it will come out in such shape that any member of the community will get good out of it. Let us follow a piece of food on its journey in the body.

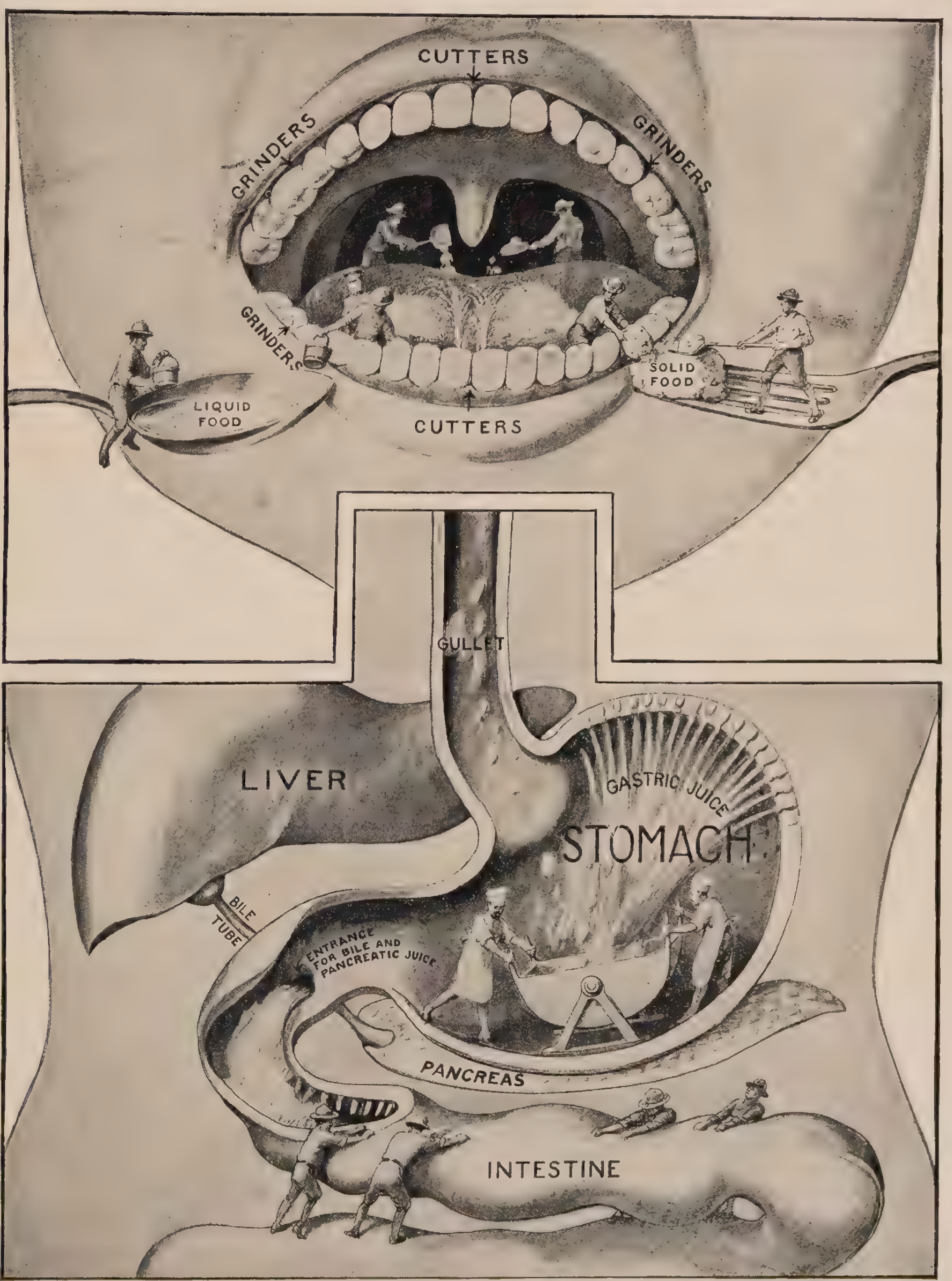
THE MILL IN THE MOUTH

This solid piece of food enters the factory of the mouth. Here it is pounded in the mill between the teeth. Of course no little men are set on the points of the teeth as they have been drawn in the pictorial diagram by our artist. But there was a reason for putting them there in the picture. Whenever you see these little working figures inserted in any of these diagrams, you know that they represent some life force which keeps the machinery operating. You and I are responsible for the working of this mill. This much Nature has trusted to us. Smooth, well-shaped millstones have been set on the upper and lower jaws for cutters and grinders, and the job of keeping them at work has been left to the owner of the factory. The mill in the mouth used to have more to do than it has now. Modern civilized man finds it easier and pleasanter to have his food ground and prepared for him outside the body and presented at the door of the mouth in nice, soft form, so that it requires little labor on his part. The result is that the mill does not get so much use as it really needs to keep its stones in good condition. We of the twentieth century have to take a great deal of care to keep the mill clean and in good repair. If this is the only part of the whole chain of food factories which it is left for the owner to attend to, it behooves him to keep it in good order and make all the use he should of it, does it not?

SIX CHEMICAL LABORATORIES AT WORK

Below the floor of the mouth (down in front) and up in the cheeks (in front of the ears) are six chemical laboratories, where the liquid called "saliva" is being manufactured. The chemists take ninety-nine parts of water and

THE BODY AS ARMY AND NAVY



THE MOUTH, THE RECEIVING STATION; THE STOMACH, THE COOK'S QUARTERS

Food, received at the mouth, cut, tasted and mixed with saliva, is passed on down the gullet to the stomach. There gastric juice is turned on it, and it is churned before it is passed on, mixed with bile and pancreatic juice, into the intestines, where the process of digestion is completed as it is kneaded and pushed along by a muscular contraction.

put into it some very powerful chemical agents. Then at the touch, or sometimes merely at the sight of food, the faucets are opened or the fountains are started, and saliva is poured into the mouth, where it will mix with the food. Being a liquid the saliva will moisten the food and work with the teeth in reducing it to a soft pulp. Dry food will not go down the food tube. The gate at the back of the mouth factory will not let it by. It must be moistened, and the saliva is what will do that work. But water alone might do that. Why six chemical laboratories, you ask? The food factory has more to do than change the form of the food from a solid into a pulpy liquid. All the starch in the food must be changed into sugar, and the first stage of that change must be made here in the mouth. In the saliva as it comes from the laboratory there is something that will make that change.

A GOOD MIXER

Right here you are to be introduced to the first of a long line of workers which you are going to meet all through the food factories. It is not quite fair to picture them as persons, even in our story way of telling of this process, for they are not alive. But they certainly act as if they were alive, or rather they bring about results that seem like those which living workers would accomplish. We shall call them the "good mixers."

Have you ever been at a party where everything dragged? The place was all right, the guests were nice people, the host and hostess were doing everything they could to make things go well. But the party would not go. The people would not mix. They just sat about and waited for something to happen. And then some late comer arrived who was bubbling over with fun and energy. He was not shy or afraid of speaking out loud or of starting something. Before he had been in the room five minutes the whole look of the party had changed. People were talking to each other. Instead of sitting stiffly in chairs around the room, they were in a group, playing the game that the host had been wanting to start but had not quite known how to manage. That one person had made all the difference. He was a good mixer, as they say. He liked everybody and everybody liked him, and people began not only to talk with him but to talk with each other and enjoy each other under the spell of his presence.

FROM STARCH TO A SUGAR

There are good mixers in the world of molecules and atoms, just as there are good mixers at parties, and they do exactly the same work. One comes along in the saliva and mixes with the food in the mouth. Suppose it finds a bit of potato. Potato is a starchy food. And starch is put together in a certain way. There are always six carbon atoms, ten hydrogen atoms, and five oxygen atoms. Every little bit or molecule of starch in the potato is put together that way. But no cell in the body, no member of the great hungry community that is waiting to be fed, could or would touch that starch. The cells want sugar, and sugar is built a little differently. It has carbon and hydrogen and oxygen, but it has two more hydrogen atoms and one more oxygen atom in each molecule than starch has. That little difference may look small on paper, but to a hungry little cell it is all the difference between what it will and can eat, and what it will not and can not eat. Before reaching the cell, that starch must be made over. Now water has just what starch needs to be changed into sugar. It has two atoms of hydrogen and one of oxygen. But if water and starch are put together, they behave like the people at the party before the last guest came. They sit stiffly by or walk around each other without a look or a nod, and they will not mix. They act as if they had no interest in each other. Then our friend, the good mixer, whose name happens to be "ptyalin," comes along in the saliva, and presto! the starch in the food and the water in the saliva mix and form a sugar. The sugar does not have any ptyalin in it. It is made up of carbon, hydrogen, and oxygen, in certain proportions. What has happened is as if the good mixer at the party, after he had got things going well and everybody into some game, slipped away himself and left the people to enjoy themselves together. But he has done his work. All the others have come together.

The good mixer in the saliva does exactly that. The water and the starch would not mix if the ptyalin were not there. When it is there, they mix, but the ptyalin does not mix with them.

All through the body we shall meet these good mixers which come along in some liquid, split two groups of atoms apart, stir them up, get them to mix with each other, and then send them on their way. Their family name is "enzymes." They are retiring in their habits. They do not stay in the limelight where they can be easily observed. It is only very lately that any one has known they were there. But they do a very important work in the community. And it is the chemical laboratory of the salivary glands that sends them out in the saliva, so that they can get to work on the food in the mouth.

FOOD INSPECTION

By the time the food reaches the back of the mouth and is waiting there to be permitted to slip down the food tube into the stomach, it is in much better form for passing on than when it came in at the open door of the mouth. Here it must pass inspection. It has been inspected by taste buds in the lining of the mouth and on the tongue. (See "Our Servant Taste," page 216.) At the back of the mouth lies the soft palate, which can be plainly seen in the diagram on page 335. If the food has been well chewed and pounded and dissolved into a liquid form, it will slip past the soft palate without a protest. But if it still has solid pieces of material which would be unpleasant in the stomach, the inspector at the soft palate gate will raise a protest. This gate is opened by the act of swallowing, which opens the food passage wide and lets the food slip into the throat. Did you ever try to swallow a good-sized pill? If you have, you know how hard it is to get it past the soft palate gate. It will be thrown back into the mouth for further treatment until by drinking water with it you manage to wash it by this gate without the inspector's observing it. The inspector can often be cheated into letting food past if it is swept by on a stream of water. But when we know what the food factory in the mouth will do for the food if we will but give it a chance, we see that it is hardly fair or wise to fail to make use of it. If we will only let the food stay in the mouth and set the teeth to chewing it, the saliva will do its work and it will pass the soft palate inspection without a question.

Photo by Wm. L. and Irene Finley

This bird has just swallowed an orange and it is making its slow way down the throat.

Then, if the food get past the air gate of the lungs, which should have been shut by the act of swallowing, it has passed beyond our control and started on its long journey within the body.

ON THE WAY — THE ENGINEERS

The factories of the food system are connected by a long food tube. This tube is fitted to serve as a muscular pump, expanding and contracting to push the food along. We may think of the cells which attend to this matter of transportation as tiny engines, set very close together, which are managed by living engineers. The engines are built into the wall of the tube. They are only one five hundredth of an inch wide. It may take a million or so engines united into muscles to push the food along an inch or so of tube. This is true not

only in the part of the tube between the mouth and the stomach but throughout its long length. In our long-necked bird friend in the photograph we can see an orange on its way. Woe to us if such a lump got into the human gullet! Not even the millions of engines could push it through.

Lock gates (not shown in the diagram) open to let the food trickle into the stomach. Eight or nine seconds have been consumed in its passage from the first food factory to the second. The good mixer, ptyalin, has traveled along with it and will stay with it in the stomach for a considerable time. Saliva digestion does not stop in the mouth. If the food has been well chewed a good supply of saliva has been mixed with it which will accompany the food and continue its good work. This leaves less work to be done by the aid of the stomach than as if the food were hastily washed down on a stream of water before it had been properly prepared.

THE SECOND FOOD FACTORY — THE STOMACH

In the second factory, the stomach, the food will stay for some time. There are two ways of breaking up a solid chunk of matter. One is by applying outside force, that is, by pounding, crushing, or shaking it. That was done in the mill of the mouth. The other is by treating it with other substances which will start up chemical action in it, so that it will undergo changes in its make-up. That, too, was done in the mouth by the action of the saliva. The same kind of double treatment is given to it in the stomach. It is never let alone while it is there. In the upper part of the stomach, immediately after it enters the factory door, it is less tossed about than it will be below. But in the middle stomach it is shaken up as if in a churn, and in the lower stomach the walls contract and expand, pushing and pulling it along as they did in the gullet. After all, the stomach is nothing but an enlarged part of the food tube. Its walls will expand to take in quite a little food, and will stay open to hold it and work on it. But when the food has been passed along, the stomach will contract again to be much like any other muscular tube.

Here, too, another group of chemists have been at work and have prepared another kind of liquid, gastric juice, which they pour upon it. Gastric juice is made in thousands of little skin bottles, each set in the stomach wall with the open end in the stomach. From each bottle the juice pours out. Again, as in the case of the saliva, the chemists have used ninety-nine parts of water to one part of something else; but again, the "something else" is very important. The bottles in different parts of the stomach make slightly different liquids. But there are, besides other chemicals, two of the "good mixers" which get into the food and pull it to pieces and put it together again in different simpler combinations. The whole work of these factories, one after another, is to get food into simpler and still simpler form, since the hungry, waiting cells cannot digest fancy mixtures. It is only a very simple liquid which suits their taste and needs.

AN ACCOMMODATING FACTORY

Food stays in the stomach from thirty minutes to two or more hours. This depends somewhat on how much comes in at once; also, on how active the stomach is, and what is going on in other parts of the body. The work of the stomach is important but chiefly preparatory; the finished product is not turned out here. When the food has been treated here, it is held and let out only gradually through a carefully guarded lower gateway at the rate that is desirable for its reception in the next factory, the intestine, which is the busiest factory of all.

The stomach factory is very accommodating. Even its size is adjustable. It can be large or small, holding a good deal of food or hardly any food. The workers go on duty whenever food is sent down to them and work very hard on it. We who are the owners of this factory should take thought for them and let them have their rest times. If a person eats a little at a time a great many times a day, or is always eating between meals, the stomach workers get no chance to rest. They are very long-suffering. But do you wonder if they sometimes rebel when their owner eats too often?

THE MOST IMPORTANT FACTORY OF ALL — THE INTESTINE

From the stomach the food is sent in a slow, trickling stream, drop by drop, into the intestine. This is a long, winding tube factory. Here again, as in the lungs, Nature has saved space by turning parts back on themselves. This factory is twenty feet long; yet it is packed away in comparatively small space. Here a new set of chemists have their chance at it. In the first section (the loop shown in the picture), which is sometimes called a second stomach, two liquids are poured in, — bile from the liver, which helps to break up the fats, and pancreatic juice, which comes in from the other side. This latter juice is very important, as it has at least three of the enzymes, or "good mixers," in it. Nowhere do these active agents get in more lively work than in this factory. Food may get past the saliva chemists only partly digested; it may slip along through the stomach without being fully broken up. But here it cannot escape. These three mixers in the pancreatic juice do whatever has not been done before. Here, too, the food is kneaded and pressed and pushed along in a way that keeps it in good condition.

Most important of all, in this factory the food becomes ready to be taken into the body. Through the walls of this tube the liquid food as it passes along is absorbed into the body. In the lungs there were thin walls with blood on one side and oxygen-containing air on the other; and the oxygen got through into the blood. The thin walls of the intestine, some eight or more square feet of surface if they were spread out flat, have the food liquid, called chyle, on one side and blood flowing in tiny capillaries on the other. As you would suspect from what you already know, the blood picks up the food here in somewhat the same way that it picked up the oxygen from the lungs.

THE ARMY OF SORTERS

It is a real community business, this taking the food liquid through the walls. If the cells that do it were not alive, the thing would not be managed so well. Here are hundreds and thousands of little living cell workers whose sole business in the body community is to pass the food through. An ordinary piece of dead skin would not do at all. Not even the most learned student can tell just how these little living members of the body community manage it. But they do it. And the river of blood passes away from the trip around the winding factory walls laden with food supplies for the body.

There are two kinds of little cell folk in the wall. There are those whose work has been described. They are busy about their business of turning food into the blood stream. Another kind of workers are equally occupied turning food into another set of tubes. At this point in its circuit the blood stream is ready to take up all of the food liquid except the fatty parts. The blood stream is on its way to the liver. Apparently fats would interfere with the work of the liver. So they are sent on a detour. From the walls of the intestine there runs a piping system especially designed for this fatty liquid which travels past the liver without going through it and empties its contents into a vein further up in the body. From this vein it joins the rest of the blood stream, going directly to the heart. The marvel is that as the food stream passes along, the little living cells are so cleverly contrived and managed by their great engineer, life, that they part the stream and turn one kind of liquid into the blood immediately; the other, into these tubes which will carry it more directly to the heart. If the cells were not alive, the liquid could flow into any pipe. But the living cells are so contrived that they switch it into the pipes where it belongs, much as two workers might sort two kinds of candies that were passing them on a moving table or belt. One takes one kind, the other appropriates the other. Simple? Yes, when it is done. But a mightily clever piece of community work.

We have traveled only a short distance along the food tube as it extends through the body. We are imagining that the particular piece of food which we are following is picked up quickly through the walls of the intestine. All along the twenty feet of this tube factory the food received from the stomach is being sorted, and whatever is useful to the body is being taken from it. Whatever is left in it is

waste material which will be discharged with other waste products from the body. The community has a carefully regulated sewage system, as well as this food delivery system. Our interest is to follow the food to the hungry cells which await it.

THE LIVER — A FACTORY AND STOREHOUSE

Our piece of food has long since become liquid. It has been divided in the walls of the intestine factory, and one part has been turned immediately into the blood. Let us follow that part. The blood vessels which flow around the stomach and intestine all empty into a great vein called the "portal vein," which runs into the liver. In the diagram on page 335 you can see what a big factory the liver is. There is more blood here during a given moment than in any other organ of the human body. This is because it is not only a factory but a storehouse, too.

Every house must have a pantry; every community, a storehouse. If food were poured into the different working parts of the body as it is delivered to the first food factory — now a big supply, then none at all, and again another big supply — the workers would be deluged with food at one moment and starved at another. As the blood flows through the liver, there is taken from it much of the sugar just received in the food liquid from the intestine. This sugar is stored in the liver in a compact form for future use. The liver is also a chemical establishment with some of the "good mixers" in it. Important work is done on the food before it is allowed to pass on in the blood. Waste products which the cells could not utilize are disposed of by being sent in the bile to the intestine. But the most important service rendered in this factory is the food control here practiced for the whole body community. From its warehouses food is doled out in a regular, steady supply of such rations as the members need.

From the liver the blood flows out in the regular circuit, carrying the food to the heart and to the cells. So, at last, after its long journey, our food is ready to be delivered to the hungry working cell.

THE LAST STAGE OF ALL

The food which we are following is now in the blood, sweeping along on that swift stream. But the blood flows in a set of closed tubes. How then will it reach the cells? It will be drawn through the walls between which the blood flows and be floated to the hungry cells. Not only will the blood act as carrier, but another liquid called "lymph" will play its part. All through the body run the lymph vessels, which are not unlike, in some ways, the blood vessels, and all the body is permeated by this liquid until it has been said by one writer that the cells of the body actually live in lymph, lying in it as a fish lies in water or an animal moves in air. Test this liquid lymph and you will find that it is very like the real river of blood on which the red corpuscles and the white corpuscles float. In the color page showing the movement of the blood you saw how beneath the corpuscles there ran a colorless stream. It carries the food, and it oozes through the walls. Lymph, as it is found in lymph vessels, is not quite like the blood stream. It gets some of its fats direct from the other piping system which makes the detour around the liver. But you will not go far wrong if you think of it as quite like the blood stream without any of the oxygen-carrying corpuscles.

It would take us too far afield in our study to follow out the course of the lymph and examine its vessels. It does not dash about the body as does the blood. It is a slow-moving liquid. But it does move, and in moving it serves two useful purposes. It brings the food within the reach of every part of the cell, and it takes away the waste of which the cell must make some disposal. Besides sharing with the blood as a food delivery system, the great lymph system acts in a sanitary way for the disposal of sewage. It gathers up the waste and carries it along through a system of tubes which finally unite in great pipes and empty into veins near the heart. So the lymph which comes out from the blood carrying food goes back to the blood carrying waste. In some of the lower animals the lymph or food liquid is kept separate from the blood, which becomes simply an oxygen-carrying liquid. In the human body the blood has both, but the red

corpuscles are hurried on their way while the food liquid oozes through the walls and wanders over the body, then returns with its waste to be swept into the swift blood stream.

IN REVIEW

We have been through so many factories and down so many winding ways that it will be good to think back and see exactly what happened to the piece of food with which we started. It was pulled to pieces, dissolved, mixed, and re-mixed in the first food factory, the mouth. It was let through the gate by swallowing, and it slipped down the gullet into the second factory, the stomach. There it got once more the two kinds of treatment, mechanical and chemical. It was shaken and churned, and it was sprayed with chemicals with which it was mixed and re-mixed anew. The third food factory, the intestine, received it after it had waited in the stomach until its turn came to trickle slowly into this tube factory. On the way, and within this factory, it was treated again to the lively work of enzymes, "good mixers," and became a liquid which the cell members of the community would absorb. Any waste contained in it was left to travel along the long tube of this factory, but the food was pressed by a rapid motion against the wall of the factory. There it was sorted, the fat part going off on a detour around the liver to be poured into the blood at a later point, the rest being received into the blood and delivered at the fourth food factory, the liver, where it was treated again and stored for a time until the cells of the body needed it. Then it was sent along in the stream of the blood and drawn through the walls and floated to the hungry cell, where it was eaten.

WHO DID THE WORK?

The food got through in proper form to the needy cell. Who did the work to make it ready? That was the community part of the job. It was not simply machinery that prepared it, any more than it is simply the hot stove that prepares the dinner for you. To get that food to the cell, there had to be chemists working in laboratories connected with every factory to manufacture just the liquids needed to change it from its very complicated form into the simple sugar or fat that the cell would eat or use. There had to be engines, manned by life, to keep it shaken up and moving and to push it along the way. There had to be gatekeepers and guards at every door to let it through at the right time. There had to be inspectors to make sure it was in the right form to pass on from one factory to another. There had to be sorters to pick it over and send the different elements of it in the right direction. There had to be packers to store it, and watchmen to report when it was needed and start it on its last journey to the hungry cell. A big corps of workers, some skilled and some unskilled, to see a piece of food through to the cell that needed it, is it not?

Oh! but that is just a story you are telling about it, you may say. The food goes through the body, but there are not really little workers all along the way to look after it. Are there not? They are not little men like those in the pictures. That we grant you. But if those cells that did all those things were only machines and were not alive, the things that happened to that piece of food would not happen to it. Read the physiologies if you think this is all made up for a pleasant story. Every once in a while you will find a phrase like this: "No known laws of mechanics explain this movement. It seems to be due to a mysterious power in the living cells themselves." Or again: "This process is not very clearly understood. It happens only with living cells." There it is. Life is at work, that life the wonders of which we are following in this book. It is the life in them that makes these cells able to do these wonderful things. If you and I choose to talk about these cells as if they were little separate members of a great big community, and to treat them as if they were alive, some people who do not know very much may smile at us, but those who know more of the miracle of life as it works through a million cells will listen with sympathy and understanding. When you are watching with wonder the miracles which life performs, you will always find yourself in good company, for the greatest scientists are those who look on at life with the greatest wonder.

WHEN YOU CUT YOUR FINGER

Of the events that took place in the body community.

ONCE upon a time — which is the way all stories should begin — you cut your finger. It bled a good deal. You washed the cut carefully, put some disinfectant on it from a bottle which you keep on hand for such emergencies, and bound it up with a clean bandage. Soon the place healed over. For a time there was a slight scar. Then even that disappeared, and the place was "as good as new." That is all that you had to know about what was happening in your body community when this accident befell you. But you may know a great deal more if you would like to imagine yourself as having been an onlooking member of the community, right on the spot the moment that skin was cut and ready to journey in any direction where things were happening.

ON THE INSTANT

Perhaps the cut was made with the blade of a knife which slipped in your hand. It cut through some capillaries and one very small vein. The blood stream of the body was flowing through all of them. This was on its way back to the heart; so it was bluish blood. But the minute the bluish blood met the air, the corpuscles with their hemoglobin picked up oxygen from the air and turned red. The blood stream moves rather slowly in the capillaries and veins. Still it was moving fast enough to let a good deal of blood run through the opening that had been made in the walls of its circuit.

But the instant that cut was made, things began to happen in the community. Between the capillaries and in the skin walls run nerves. They are connected with community headquarters. They sent word instantly through the finger, up the arm, and to headquarters that there had been a break in the wall. You felt pain when that message got through to the brain.

But pain was not the only response at headquarters. Word was sent back along other nerves to the nearest substations to send an army of defense to the break in the wall. From all around that region the army began to gather. The blood stream began to fill with the soldiers for the defense. The capillaries became larger as their walls were stretched. The soldiers which happened to be in the blood stream as it came flowing along began to work at once. Others hurried there in increasing numbers as fast as ever they could.

NATURE'S FIRST AID — THE BLOOD CLOT

Before many of the defenders could get there some other things had begun to happen. The blood had begun to clot. This is Nature's protection for the river of life so that it does not run away when there is a break in the wall. The cut was so small that there was no danger of your losing much blood before the leak could be stopped by bringing the skin together again. But if an artery had been cut a great deal of blood might have been lost. You remember that we said that there were blood plates or platelets always floating in the blood stream. They seem to have to do with this business of clotting. When the accident happened some of them were on hand, others were coming up every instant, and they went right to work. It seems likely that there is in the blood a ferment, one of the "good mixer" family, that helps on the work. Anyway, the blood began to thicken, and kept right on thickening until the flow stopped. If a cut is small, such a blood clot will in time form a protective covering for the wound.

THE ATTACK

That was not all that was happening. The hand was not quite clean at the place where the cut came. The blade of the knife was not

quite clean either. There were hundreds of tiny microbes or germs all around the spot. They are little living things — plant or animal, as it happens. At such a moment they are an attacking enemy, and you have given them the chance to invade the body. Instantly the skin was cut, their chance came to make an attack. They fell into the blood stream. They began to push into the tissues of the skin.

OUTSIDE AID

Here you as master of the body came into the fight. You knew that the microbes were there although you could not see them. You knew that they would try to get into such an inviting open place and that they could do a great deal of harm. You had been taught that liquid disinfectant was a microbe killer. So first you washed out all the dirt you could with water, and then you put on some of this disinfectant. The place stung a little when you put it on, for the cells and nerves of the skin got some of the acid, too. But a great many microbes were killed, and any dirt which had stayed in was washed out. Then you wound the place with a clean bandage so that no more microbes could get in and so that the skin walls would be held together as closely as possible. That was all you could do. Perhaps you said to yourself, "Now Nature will do the rest." That is what you felt, whether you said it or not. But how would Nature do it?

THE DEFENSE

If you followed along on the trail of the message which took the news to headquarters, and then came back with the reply messages which were sent to all the region of which the skin of the finger was the frontier, you saw the soldiers of the defense crowding from all sides into the blood stream to be carried rapidly to the point of attack. And as you looked at them, what were they but our old acquaintances, the white corpuscles? When we examined the blood stream, we saw hundreds floating on it. If we had stopped to look at the stream of lymph we should have seen hundreds more floating on it and wandering off here and there in every space they could find between the cells. They are the defenders of the body community. They are being rushed to the rescue.

Follow them along to the spot where the skin was cut, and see what they do. Each one engages in single combat with one of the germ enemies. The method of attack is curious. Just as the amœba took into itself the food it met by flowing around it, so the white corpuscle flows around the microbe and takes it into itself. If it had a mouth we could say that it swallowed and ate its enemy. The enemy disappears in its embrace. If the corpuscle is the stronger of the two, the microbe is destroyed and digested as food. Sometimes the enemy wins. The corpuscle cannot quite swallow or manage it. Then, after the surprisingly swift manner of all such little fellows as germs and microbes, this microbe begins to divide and subdivide into other microbes. But remember that meanwhile more defenders are coming to the rescue. One champion, one white corpuscle, may go down to defeat in its single encounter. But others will be ready to take up the battle. Multiply the single combat by hundreds of thousands, and you have what takes place when an attack is made from without. You helped the army of the defense all you could by killing the microbes on the surface and washing out any dirt. But it remained for the defenders to battle with the enemy and to keep on battling until the fight was over.

YOUR DISCOMFORT

The skin grew red around the cut in the hours after the accident happened. Very likely you felt pain and soreness. That was because of the blood that was rushed there. All the near-by capillaries and other tubes of the blood system had their walls extended as far as they could be to take care of this extra blood supply. Those swollen tubes pressed on the nerves, and they sent word of their condition to the brain. Redness, swelling, heat, and pain — these four things occur when nerves and blood vessels are injured and an extra supply of blood with its defenders is rushed to the spot. We say that there is inflammation there, or that the place is inflamed.

HOW IT HEALED

A great many cells were destroyed along the line of the cut. The repair squad of the community began instantly to rebuild those cells. They drew on the food in the lymph for this purpose. You know for yourself how fast new skin will grow over a place that has been cut. If the white corpuscles can keep up a winning fight against the germs, the repair squads can attend strictly and without interference to their business of rebuilding. In a healthy body that is what happens. But when you tied the bandage and said, "Nature will do the rest," did you suspect what a fight was going on underneath? Did you realize what a fortunate thing it was that the body was a community with repairers and defenders and a headquarters which could order them hither and thither to repair the damage? Perhaps you did, and perhaps you did not. At any rate you will know all this the next time you cut your finger. And be sure to help the defending army all you can by washing the place clean and putting on disinfectant, even if it does sting.

WHEN YOU HAD A COLD

Of the invaders that forced an entrance into the body, and of the army of defense that came to the rescue.

YOU had a cold last March, or we will suppose that you did. It began in the head. You got chilled one day standing on a windy corner waiting for a car. This chilling of the skin made the blood vessels all over the surface of the body contract. When this happens, the movement of the blood stream does not proceed as regularly as it should. Blood tends to gather in certain places. This time it probably gathered in the skin lining of the nose and throat. If you had been feeling at your best, this could have happened and you might have escaped a cold. But you were tired and your physical forces were not quite up to par. So the blood vessels in the lining of the nose and upper throat kept more blood than was usual with them. This gave germs which had poked their way into the nose exactly the chance for which they had been waiting. They began to thrive.

WHAT THE SYMPTOMS MEANT

At first the cold was only an inflammation of the mucous membrane which lined the nose. Too much blood was staying in the capillaries that run through this membrane, and they were swollen. White corpuscles rushed to the rescue to drive back the offenders, but the enemy were for the time being too much for them. The little sweepers of the skin, the cells which keep their hairs brushing back and forth to catch and drive back the enemy, were so weakened that they could not do much. The chemical factories which supply moisture to keep the nose passages in good condition became affected by the conditions about them and sent out a great supply of mucous fluid. (Your nose began to "run.") This did some good, for it helped to flood the enemy out. The white corpuscles fought the germs and in the battle millions of the defenders fell victims to the germ enemies. So the passages became clogged with a great deal of matter. It was difficult for the air to get through to the lungs. The lung bellows made every attempt to keep the airways clear. They struggled along, giving extra violent movements in an attempt to drive out the stuff that was clogging the tubes. (And you coughed.)

The invading germs produced poisons which worked their way into the blood stream, and spread the trouble into other parts of the body. (Your head ached, and you were sore all over, and tired.)

QUICK RECOVERY

But the army of white corpuscles kept up their work. If they lost one trench, they

fought the harder at the next. The laboratories of the nose kept on pouring out the liquid which should wash away the germ. The bellows of the lungs did their best to drive out the enemy and keep the air passages clear. Finally the enemy weakened. The defenders moved forward until they had captured all the home territory once more. The casualties were all thrown out through the nose and mouth. Peace settled down once more, and the troops of white corpuscles withdrew into the blood stream and the lymph stream. (You were well again.)

OTHER POSSIBILITIES

This was a great victory because the invaders were kept in the restricted area of the nose and throat. If they had succeeded in getting down to the bronchial tubes, they might have made far more trouble, for those tubes are very small and therefore more easily inflamed and stopped up. If they had reached these bronchi, you would have had bronchitis. Or they might have driven on down into the

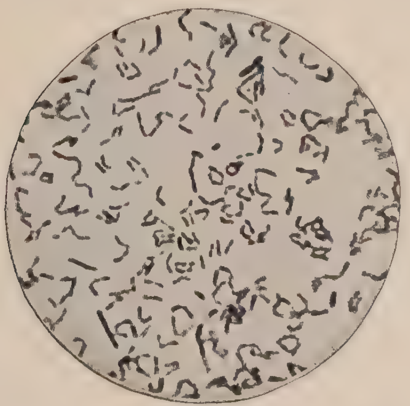


Photo by Philip O. Gravelle
TUBERCULOSIS BACILLUS
(Magnified 1200 Diameters)

lungs themselves, into the walls of the air cells, then you would have had pneumonia. Pneumonia comes only when a pneumonia germ attacks the surfaces of the air sacs. But there are always pneumonia germs in the mouth and throat. That is one of the curious facts about the body community. Enemies which might harm it are always living in or near it. But when the community is running well, they have no chance to do harm. The moment inflammation sets in, their chance comes. The danger of a cold is not in the cold itself. A cold with its inflammation of the delicate skin of the mouth and throat, and with the danger of this inflammation spreading into other regions of

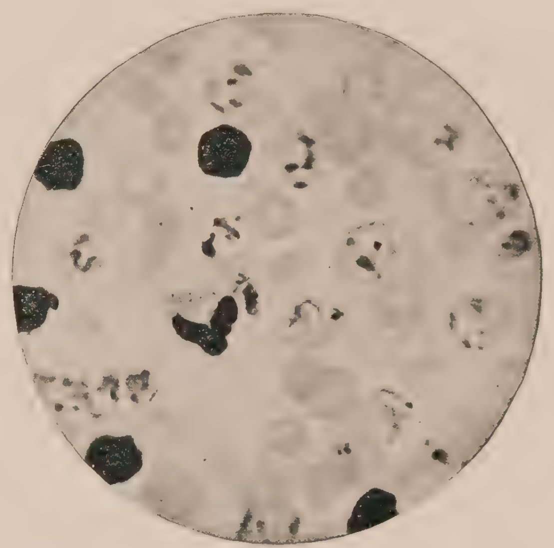


Photo by Philip O. Gravelle
MALARIAL PARASITE ON RED BLOOD CORPUSCLES
(Magnified 1000 Diameters)

the air chambers, gives the opportunity for the germs which may be lurking about to get in their dangerous work. Germs grow on such an inflamed skin as plants grow in rich soil, and they grow so fast that it takes a tremendous army of defenders to keep up with them. If you have a germ illness, the doctor will test your blood to see how well it is supplied with white corpuscles. It is wonderful how such a community will use every device to assist the cell members in the attacked places. The body is such a close community, with all the parts so connected, that a great deal of assistance can be rendered to any weakened part. But the best way is to attend to any such attack at once, before it spreads over too large a territory. Here you could help by keeping still, resting, not loading your stomach with too much food, and in other ways giving the defending armies every chance to concentrate on defense and win.

There is another germ which sometimes takes advantage of a cold to attack a person. This is the germ that causes tuberculosis. We have a picture of tuberculosis germs here. They are little bacteria such as can only be seen under a microscope. Yet they are among the most deadly foes of the human body. These germs will travel anywhere in the body after they gain an entrance. They find particularly comfortable lodgment in the lungs, especially if the surfaces are inflamed from a cold. But the germs must get in and stay in before a person can have tuberculosis. All the ways in which we are taught to avoid this disease have one purpose back of them, namely, to keep the germs out.

The tuberculosis germ can be carried from person to person by contact. It can be breathed in with dust which has acquired it by some person's unpleasant and dangerous habit of spitting. It can come in if a person coughs it out into the air in his breath and another person breathes in almost instantly that same air. It can come in with milk from a tuberculous animal. But if the germ is kept out, there can be no tuberculosis. If it gets in, a healthy body will usually get rid of it, for here again the defending armies will set about their work. All germ diseases are fought by the white corpuscles, which seem to multiply at need. In illness it has been found that there will sometimes be ten times as many as when the body is in health.

One point will have become apparent to you in these stories of the way the body responds to an emergency of accident or cold. The body tends to keep itself healthy. In case the balance of health is temporarily disturbed, the whole community works to return to normal. In the matter of colds, it is for you to give the body every chance to recover itself. When you understand how you take a cold and what is happening in your body when you are throwing it off, you will learn both to avoid having a cold and to give yourself every chance to get over it promptly if you should have one.

THE HEATING SYSTEM

How the body is kept at an even temperature.

If we tried to visit all the workers of the body community who have to do with the heating system, we should have to travel from headquarters in the brain to the tips of the fingers and the soles of the feet, back over the whole skin surface and into the heart and around with the blood stream and up and down the muscles until we had inspected every remotest part of the community. It seems simpler to call the roll of the heat managers as one might summon the foremen of the different departments of a factory, and let each tell what his group does.

THE BODY TEMPERATURE

Before we do this, let us see what they accomplish as they work together. They keep the body at the same average temperature all the year round. In zero weather or hottest summer weather the thermometer which the doctor slips under your tongue for the taking of your temperature will have the same reading, — 98.6 degrees Fahrenheit, or thereabouts. If you have ever had anything to do with the heating of your house you know how hard it is to keep the temperature of the rooms always at 68 degrees, regardless of how cold it is outside or how quickly the weather changes. And in summer when the heat of the outside air runs the thermometer up to 95 and 98 and 105 degrees, you do not pretend to be able to keep the rooms still at 68 degrees. But that is what is accomplished in your body. Peary at the north pole and a South American at the equator might each take his temperature and find it the same, regardless of heat or cold. It is a wonderful system Nature has worked out in the body by which all the workers manage to fit their activities together to get this result.

MUSCLES AS HEAT PRODUCERS

First, let us summon those who run the furnaces and keep the fires going. They would come trooping from all over the body, an army

larger than we could count; but we have agreed to have only representatives from the different departments. These are the stokers who keep the muscle engines going. Every cell in the body is a tiny slow-burning stove; those of the muscle engines are the more quick-burning heaters. It is the business of an engine, their foreman will tell you, to transform one kind of energy into another. The muscle engine turns chemical energy (from the food fuel) into mechanical energy (for movement) and heat energy. All machines, whether of iron and steel or of flesh and fiber, work more or less wastefully. Even if they are designed to produce as much mechanical energy as possible, they will be able to turn only a part of the energy from their fuel into that; a considerable part will always appear as heat. From the point of view of what is wanted, namely, work, the heat thrown off is merely a by-product. As an engine for producing mechanical energy for movement, a muscle engine is only about one-fifth (twenty per cent) efficient; its remaining energy, four-fifths (eighty per cent), is thrown off as heat. Economical Nature takes this heat and turns it to good use in keeping the body within the narrow range of temperature necessary to support life. The muscle engines, which have to do primarily with locomotion and other movement, are thus one of the chief sources of heat in the body.

Do you wish proof of these facts? Your foreman will give them instantly. When you take vigorous exercise you grow very warm, do you not? Exactly. The muscle engines are all at work. One-fifth of their energy is given off for your movements; the other four-fifths of their energy output is thrown off as heat. No wonder you feel warm! When you feel cold you get up and stamp your feet and swing your arms, do you not? Surely! The foreman tells you that you are calling on the muscle engines to work harder so that they will furnish more heat. In this case you do not care so much about movement for its own sake. You start the locomotion engines for the sake of the heat they will give. Sometimes when cold strikes suddenly on the surface of the body you shiver. The foreman reminds you of that. The muscles are starting to move almost of their own accord to produce more heat. Muscle engines are the most widely distributed system of heat producers for the body. They are throwing off heat all the time, whether we sit or stand, sleep or wake; but they produce the most heat when the body is most active. When you read in the next section of "Food as Fuel," you will see what pains you must take to supply sufficient fuel for these engines.

THE HOTTEST PLACE IN THE BODY

Following close on the heels of the speaker for the muscles comes the head chemist of the great chemical factory of the liver. Along with him troop a group of representatives of each chemical laboratory in the body. Each food factory is represented by its head chemist; the glands or chemical laboratories of the brain and of other parts of the body are represented. All can show that they produce some heat, for every factory in which a chemical process is going on must for that very reason give off heat. But the liver leads all. It is the place in the body where the greatest amount of chemical action is taking place; so it is the hottest place in the body. The head chemist says that his tests show it to be often nine or ten degrees hotter than the average body temperature. One hundred and seven degrees Fahrenheit is a not uncommon reading for the liver thermometer. So hot a factory will naturally have a great part in heating the body, though not so much of a part as the more widely distributed muscle engines.

THE BLOOD THE EQUALIZER OF TEMPERATURE

From these reports it is plain that certain places in the body will be kept very warm by the work they do and the resulting heat. This is not sufficient for the comfort of the body community as a whole. Heat must be distributed. It is not enough to have a furnace burning in the cellar; there must be a piping system in the house, through which air or hot water or steam may be conducted to equalize the temperature all over the house. Again Nature is economical in its community planning. The same piping system which serves for carrying fuel and food can distribute heat;

the same liquid which bears these necessities can serve as equalizer for the temperature. You know without being told that the next representative to be called will come from the heart pump and will report on the blood stream as the great equalizer of temperature in the body. As it flows from one part to another on its rapid circuit, it warms the cold parts, grows cooler itself in the process, gets warmed again as it passes through the hotter places of the body, repeating this process again and again as it dashes up and down the limbs and through the food factories. The blood gets thoroughly heated in the liver, which keeps a great deal of blood within it all the time. At any given moment it is said that one-fourth of all the blood in the body may be found within the limits of the liver factory. Blood has been tested for heat as it went into the liver and as it came out and found to have had its temperature considerably raised. This hot blood will be cooled as it flows through the capillaries of the skin surface; it will be cooled as it comes in contact with the air in the lungs. But it is going so fast that it will soon be warmed again in the muscles and the chemical factories.

Photo by S. Leonard Bastin

A FLOWER THAT RUNS A TEMPERATURE

Just as it opens, the *Arum italicum* has a temperature which is over 100 degrees Fahrenheit.

WARM-BLOODED AND COLD-BLOODED

For a human being to realize what a difference this blood stream makes in the temperature of his body, he must look about him at the other members of the animal kingdom. He will find that mammals (to which class he belongs on the physical side) and birds are the only creatures favored with this system. They are warm-blooded; creatures farther down the scale are cold-blooded. We shall appreciate our own good fortune more if we stop to consider what this means. Lifeless matter takes the temperature of its surroundings. A stone is hot on a hot day, cold on a cold. The surface of the ground freezes or becomes baked according to

Photo by S. Leonard Bastin

HOW THE GOURD KEEPS COOL

The sun temperature is nearly 120 degrees Fahrenheit, that inside the gourd only 62 degrees Fahrenheit.

the temperature of the air. Plants follow much the same system. We have shown here a few remarkable exceptions which have a different temperature from that of the surrounding air. But these are so much out of the ordinary run as to be a marvel of science. It is evident that they have substances within them which are not quickly affected by heat or cold and which tend to keep their average temperature lower or higher than that of the surrounding air. Most plants do not. If you were to take the temperature of the plants in your garden, as the doctor takes your temperature, you would find that it was very close to that of the air.

Cold-blooded animals behave in much the same way. They are always a little warmer than the air or water in which they live, for chemical changes are going on within their bodies and the muscle action necessary for movement is always producing a little heat; but they are only a little warmer. A frog or a fish, a crocodile or a lizard takes his temperature from his surroundings. Because in the temperate zones of the globe the temperature of the air is rarely up to or above the 98.6 degrees of a man's constant temperature, any of these lower animals will feel cool to man's touch. Hence the name "cold-blooded." On a hot summer's day a lizard basking in the sunshine on a hot rock might have a temperature as high as that of a man, or even higher; but usually it will be lower. A bird, on the other hand, will run a temperature eight or ten or twelve or fourteen degrees higher than that of a human being, a temperature at which a man would have a high fever and die, and will make no account of it. Both bird and man are warm-blooded and run their own heating plants.

WHERE WE HAVE THE ADVANTAGE

When we examine these cold-blooded lower creatures to find out what is the difference between their make-up and that of mammals and birds, we find a very simple one. Birds and mammals have two-chambered hearts with no opening between. It was only a hole the size of a pinhead, as you will remember, that helped to keep the crocodile down in the scale of life. But that little leak was enough to let the impure blood stream, as it returned from the body circuit, run into the pure blood stream as it started on its way — and that made all the difference. If the two circuits cross, the blood is never absolutely pure. The pure blood stream of the birds and mammals has so much to do with keeping their bodies at an even heat that they stand out as unique among all living things. They are most active; they therefore manufacture the greatest amount of heat. A swift-flying bird of the air runs a higher temperature than a slow-moving duck of the barnyard. Cold-blooded animals must hibernate. Man with his internal furnace can live anywhere on the globe. He can survive the coldest winter provided he can find food fuel with which to keep his body furnaces going. An internal heating plant which he carries around with him makes man almost independent of the usual temperature changes of the atmosphere. Such independence has given him control of the world.

Photo by Wm. L. and Irene Finley

JUNCO FEEDING IN SNOW

He must have a good heating plant within his small body.

If birds have this heating plant, why should they migrate? you may well ask. If a bird or a bear could find sufficient fuel to keep the fires burning, either could weather a winter. For the bear it is much simpler and easier to crawl into his den and keep only enough fire going to

preserve life during his long sleep. Many birds do weather the cold blasts. The one in the picture appears entirely comfortable on a snowbank. Its furnace must be supplying a goodly amount of heat. But most birds find it simpler to set their muscle engines at work for a long flight southward and then to meet only the usual heat requirements in the warmer climates. It makes less pull on their tiny bodies, which would have to be constructed differently to run higher fires. It is a marvel that a bird is not consumed by its own heat as it is, with its constant and literally superhuman activity. There have to be very nice adjustments in the bird structure to make this fever temperature comfortable and satisfactory.

HEAT REGULATION

So far we have heard from those departments of the body which produce heat and from the heart manager who sees to the equalizing of heat. Now we come to the matter of how it is regulated. With fuel pouring in from the food supplies which we eat, with the engines and the chemical factories working harder at one time than another, with the temperature of the air in which we live varying from hour to hour and day to day, with all the thousand and one changes which are constantly taking place, how is the body always kept at about the same temperature? There are two chief ways in which this is managed: the first, by limiting the production of heat, the second, by arranging for the loss of heat.

Less heat will be given off if less food fuel is supplied. On a very hot day a person does not feel like eating as much as on a cold or cooler day. A wise person regulates his diet in summer, eating less meat and other heat-producing foods. The less one moves about or exercises, the less heat is thrown off. All these are natural and familiar means of cutting down the production of heat.

The greater part of the regulation of heat is managed in the other way, — by arranging for loss of heat. With an ordinary supply of food and ordinary activities, the body is always producing more heat than is needed to keep the temperature at 98.6 degrees Fahrenheit. Some heat is always given off in the breath from the lungs, but the skin plays the greatest part in keeping the temperature down. Its blood vessels expand and contract by the action of the muscles in them; this action is controlled by nerves. On a warm day, or if the body is warm from exercise, these skin blood vessels relax and expand. This lets more blood come to the surface of the skin, where it will be cooled. On a cold day they contract; less blood flows through them; more blood is kept in the warm inner parts of the body; the blood as a whole is less cooled. It is a very simple device, and is regulated from the headquarters of the nervous system. We have not talked much about headquarters as yet. If we were to call a manager to explain this system of heat regulation by expanding or contracting the blood vessels of the skin, that manager would come from this headquarters. He would tell how, when the blood flowing through headquarters becomes too warm or too cool, he is able to regulate instantly the amount of blood in the skin by this means. He would remind you that your skin is red when you are overheated, and pale when for some cause the blood is withdrawn. He would summon a comrade manager from headquarters who has charge of the sweat glands.

PERSPIRATION FOR HEAT DISCHARGE

When we perspire freely, heat is given off in evaporation. A drop of perspiration as it turns into a gas in the air takes away from the body as much heat as would be required to raise two other drops above the boiling point of water (212° F.). There are five hundred sweat glands on an average to every square inch of skin, and there are seventeen square feet of skin covering the body of the average-sized man. When the blood flowing through headquarters gets too warm, not only does the blood-vessel manager send out orders to the blood vessels of this great area to expand so that they can receive more blood and cool it; the manager of the sweat glands sends out at the same time orders for the sweat glands to give out moisture. The hotter and drier the air, the more rapidly does this evaporation take place, and the quicker the cooling of the body. If the air is hot and yet moist, as in the so-called

dog-day weather, the moisture does not evaporate so rapidly, since the air is not ready to take it up. Days of high humidity are, therefore, likely to be more trying from the point of view of comfort than days when the thermometer reading is higher but the air more dry.

Our own experience is constantly coming up before our minds to confirm these facts which we are learning from the less familiar point of view of their physiological cause.

IN CONCLUSION

Other heat regulators might appear with a claim to some slight effect on the body temperature. The fat producers of the body might well claim that their storing system serves to keep heat in the body by placing a layer of fat like a blanket over the heat-making organs of the body. We have heard from the most important workers on these lines. We compared our heat circulation system with that of some of the other animals. Skin control of heat was doubtless more effective with early man than it is for us who protect the skin with so much clothing. We demand less of the skin when we so protect it; but it still continues its faithful service. For fur-bearing animals the skin is less important in regulating body temperature. They depend more on the lungs. A dog pants in hot weather, and breathes more rapidly when he is running. A man will use every means of heat regulation in emergencies; in ordinary times engines, laboratories, the blood as equalizer and the lungs and skin as regulators, will keep the balance without apparent effort.

These Members of the Body Community Look after the Food We Eat

Inspectors and Guards

The smellers in the nose; the tasters in the mouth; the guards at the gate at the back of the mouth; the traffic officers in the throat who send it down the food tube rather than into the air tube to the lungs; the guards at the gate of the stomach who open the locks; the guards who open the doors at the bottom of the stomach; the sorters in the intestines; the watchmen of the liver.

Engineers and Workmen

The grinders of the mouth; the transportation engineers of the food tubes; the churners and shakers of the stomach; the packers of the liver.

Chemists and Manufacturers

The chemists of the six saliva factories of the mouth; the chemists of the gastric juice bottles of the stomach; the manufacturers of bile; the chemists of the pancreas factory; the chemists and manufacturers of the liver.

Sanitary Workers

The sanitary inspectors; the workers that dispose of sewage.

These Members of the Community Attend to a Cut

The managers at headquarters; the telegraph clerks; the workers that make the blood clot; the soldiers of the defense — the white corpuscles; the repair squad; the building squad; the sanitary corps.

These Members of the Community are Affected when a Person has a Cold

The engineers that keep the current of blood moving; the sweepers of the nose and throat; the soldiers of the defense; the engineers for the lung bellows; the transportation workers all over the community; the repair squad; the sanitary corps.

These Members of the Community Produce and Regulate Heat

The muscle engineers; the workers in the laboratories; the workers at the heart pumps; the breath regulators in the lungs; the managers of the sweat glands.

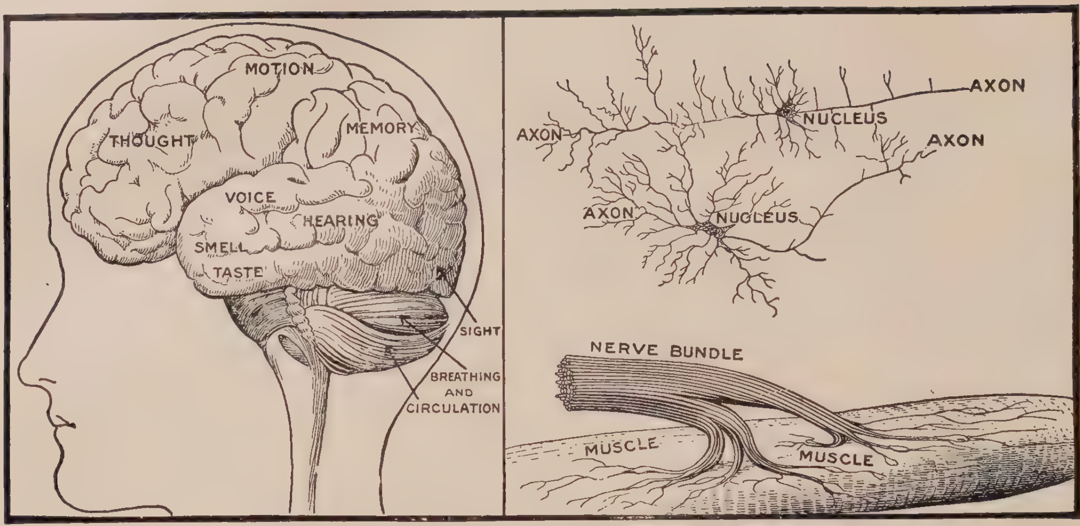


DIAGRAM OF THE BRAIN, AND A NERVE GREATLY MAGNIFIED

AT HEADQUARTERS

What happens when you touch something hot, when you walk, when you sleep, when you speak, when you remember.

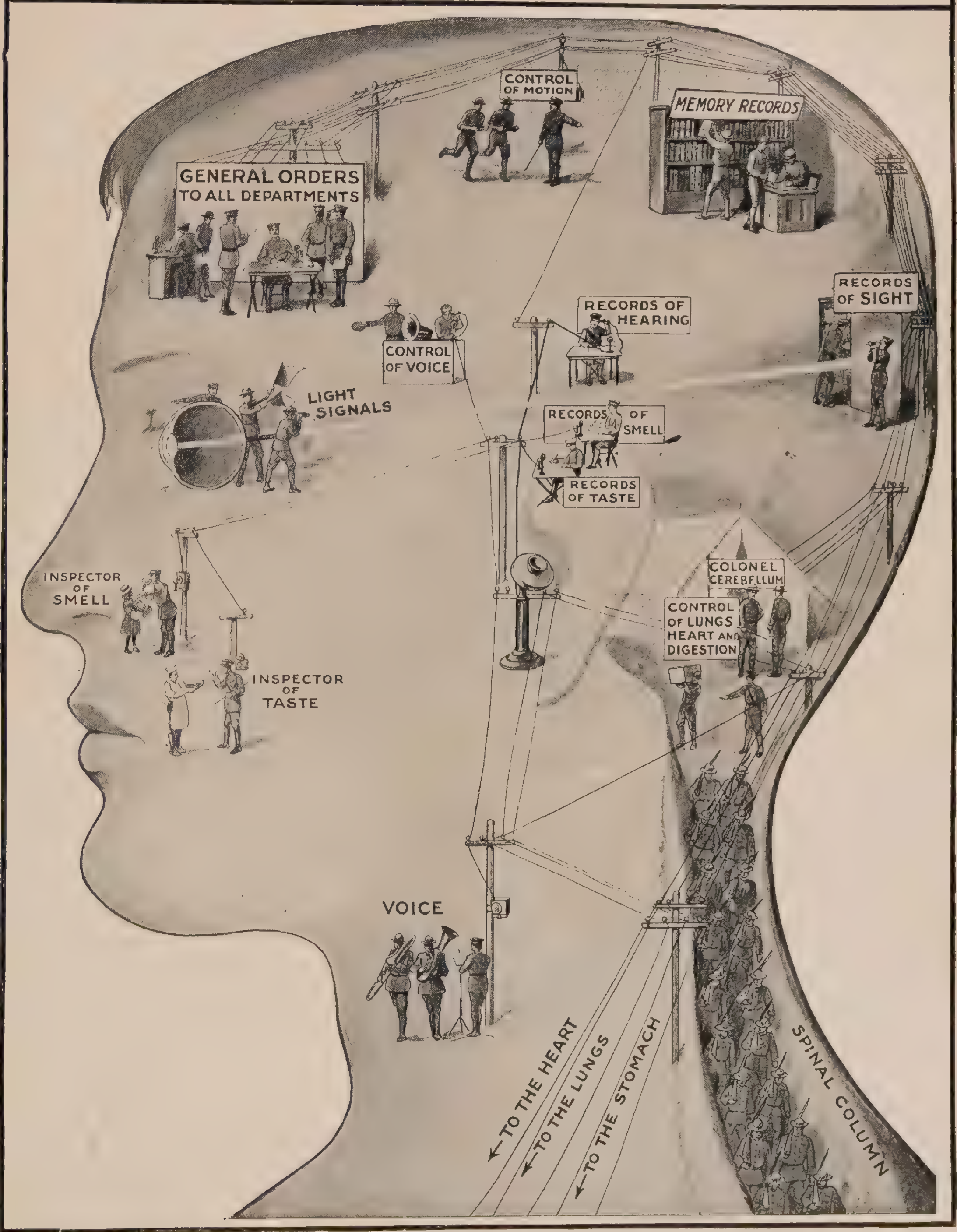
A GLANCE at these pictures shows that we have come to the most interesting place of all, the headquarters from which all the community is managed. Millions of workers in each department take their orders from this center.

Headquarters is housed in the skull and along the backbone. It has the officers and many of the soldiers of the great army which makes up the nervous system by which the body is ruled. Like all other parts of the body the nervous system is made up of cells. Each living cell might be called one of the soldiers of the army of headquarters. At the top of the page one of these cells is pictured. (It could not be seen except under a powerful microscope.) It has a center, or "nucleus," many fine branches, and one long branch called the "axon." Below is shown a nerve bundle. No one nerve cell starts off by itself, any more than one soldier walks by himself. They go in companies, making up nerve fibers or nerves. The nerve cell shown here is one of the kind that has to do with movement; so it is shown as it might run into and along a muscle and carry to that muscle orders from headquarters to relax or contract. There is no part of the body into which these soldiers fail to penetrate. They go everywhere and each keeps always its connection by its axon, or living wire, with its nucleus either in the "lower brain" or spinal cord, or in the higher brain.

As you study the picture you will see how headquarters is divided. A great deal of business is attended to from the nerve centers in the lower part of the brain at the back of the neck and in the spinal cord. "Colonel Cerebellum," as our artist calls him, lives here; or, in the language of physiology, here is the cerebellum, a small part of headquarters, its offices not larger than a lemon, but a very useful part, for it relieves the general headquarters further up of many duties. We do not have to think consciously about what is done by the management of this office. Just below the office of Colonel Cerebellum is the corridor which connects the upper offices with the spinal cord. Here the heartbeat, the contractions of blood vessels, and the breathing movements are controlled.

Headquarters is very well organized, each part with its special soldiers and its special duties. It is very complicated in its relations and interrelations, as any organization with

OUR WONDERFUL SIGNAL SYSTEM



HOW THE BRAIN CONTROLS THE BODY

Stop the life in the brain, the busy work of an army of nine billion living neurons, and the eye could not see, nor the ear hear, the voice speak, nor the finger move. Study this picture and see in what part of your brain each "power" is located. There is no receiver in the ear telephone; the receiver is in the hearing department above to which the message is telephoned. Light signals are flashed to their special department, and you see. "Colonel Cerebellum" manages many of the involuntary processes to which we need pay no attention, the beating of the heart, the digestive movements, etc. Working as an efficient army, the life in the brain masters the body and through the body the world.

nine billion distinct units (soldiers, as we should call them) functioning in the brain alone and a whole body community to manage might well be. This simple study will serve its purposes if it introduces you to the picture of headquarters as it is organized and as it controls from different regions different parts of the body. To show how this works we will see what happens when certain messages with which we are familiar in our everyday experience are sent in from the body surface. For instance, what happened when you touched a plate which you had expected would be cold and found it too hot for comfort?

TOUCHING A HOT PLATE

The moment your finger came in contact with the hot surface of the plate, you jerked your hand back. What had happened in your body community?

The skin of the hand was stimulated by the heat. The nerve soldiers in the skin whose business it was to take meassages to headquarters sent this message to the central nervous system manager. The message traveled at the rate of about one hundred feet a second. As soon as it reached headquarters another set of soldiers, who are in control of the muscle engines, sent word down to the muscle engines to start up and contract. They did so, and the finger was jerked back. This was a case in which, in all probability, the act of pulling the finger back was performed almost before, if not actually before, the message of discomfort reached the brain. The lower offices of headquarters are capable in such cases of acting very promptly in their control of the muscle engines. The response may come from this lower office before the message has been relayed on to the brain and has therefore come to your consciousness. There is a whole class of similar responses, protective and regulative in their nature, in which these lower centers of the nervous system exercise their control thus promptly without our conscious attention or preceding our "taking thought" in the matter.

It is curious to think that the driver of a muscle engine is not located right at the engine. He is back in some section of headquarters where all the drivers are massed together. He may be three feet away from his muscle, but he is quick and efficient in his control of it. There are two kinds of nerve soldiers,—those whose business it is to take messages in and those whose business it is to send messages out. The muscle driver is one of those who send orders out. But there is always a soldier to pair him, bringing messages in.

WHEN A BABY STARTS TO WALK

At some time you have watched a baby as he was learning to walk. First he managed to stand alone for a moment, balancing without steadying himself by a hand on a neighboring chair. Then one day he tried taking a step. He fell down, but he tried again and again until finally he could take one step, then several. The baby in the picture is not quite sure of himself yet; but he is much delighted with his new achievement. Well he may be, for he is driving one hundred engines.

That is what a baby has to learn to do. That is what you once learned to do. In walking, a hundred muscles are contracted and then relaxed in regular order. They have to do with the moving of the legs, with the balancing of the upper part of the body on the two supporting legs, and with bringing the body to rest after the movement has been made. All these muscle drivers have to learn to work together, as the soldiers of a company have to drill until they can move as a company, not as so many separate men. The baby is getting his muscle drivers trained. Sometimes they obey his wishes, sometimes they do not.

When the baby has learned to drive his hundred engines all at one time and keep them in perfect time and work them at just the rate he chooses, they will stay trained. He will not have to take thought for every step he takes as he is doing now. That is the joy of our system of a General Headquarters with a big staff under it. We do not know just how it is managed, but somehow these groups learn to work together without our paying any attention to them except to give general directions. When you want to walk, you simply send word to the headquarters for "Control of Motion" up at the top of the brain. A message is

promptly dispatched to Colonel Cerebellum to "walk" your body along. He does the rest. You never have to consider the hundred separate engines that keep your legs moving and your body balanced. But if you wish to attempt a new set of motions, you have to train your muscle drivers for carrying it out. If you start to learn to swim, you have to repeat the motion over and over again before it becomes quite natural and automatic, which is to say "doing itself." If this baby wishes a dozen years later to pitch for his school baseball nine, he will have to train his muscles to a wholly new set of tricks. When once headquarters learns what is wanted and the different members of the force have got in the way of working together to bring this movement about, they will be a very obedient and faithful company.

YOUR CAMERA

You have a camera — two cameras, in fact — the eyes. Each has a dark chamber, a lens, and a sensitive plate or film. But if there were no muscle engines to make the lens adjustable for near or far sight at a moment's notice, the camera would not take as good pictures as it does. If there were no muscles to move the eyeball, the front of the machine could not be turned without the movement of the whole head. (Most of the lower animals cannot roll or turn their eyes, you remember.) And if, again, those muscle engines were without nerve drivers, they would stand idle. How quickly the muscles around the camera work when the eyelids are swung shut in winking! This is what we call an "involuntary act." It happens "before we think," which means that at the approach of danger the muscle engine is set going by its driver, who has been informed of the threatening event and sends back the order to close the lids. All the adjustments for protection and focusing are managed from headquarters.

The picture is printed on the film or retina, but here again there is need of headquarters, for there it might stay on the film without your knowing anything about it, were it not for the office for sight. If you will look back to the picture of the eye on page 199, you will be reminded that the optic nerve comes from the brain to the retina. Its many, many separate nerves, or nerve messengers, carry to the office directly across the head from the eye the record of each successive picture taken on the film. In the office the records are packed away in orderly fashion, ready to be brought out at the will of the owner.

Often the office performs another service. All the offices of headquarters are closely connected. The office for sight may record

THE FIRST STEPS

that the body is approaching an obstacle, a post or the corner of a house. It will communicate that message to the offices for locomotion, which will act on the information. The records of sight are in constant use to tell a person in which direction to walk, what he is eating and drinking, who is approaching, and other facts about his surroundings. No office is called on more frequently to pass on its information.

With two cameras you might wonder why you do not see everything double. The nerve messengers attend to that. The part of the office on the right side of the brain registers the pictures which are printed on the film from the field of vision of the left eye; the part on the left side registers the pictures from the field of vision of the right eye. In the brain the two part-pictures are somehow recorded by the nerve messengers as one picture.

The picture on the retina is also flat, with no depth or distance to it. But training of our nerve centers teaches us to judge distances and see objects as solids instead of as perfectly flat. That this is something we learn to do, as we learn to walk, is shown by the fact that a person who has been blind all his life and suddenly regains his sight has no such sense of distance. All objects seem spread out on a flat surface. He finds it difficult to go up or down stairs. He puts out his hand to touch an object that is across the room from him. We doubtless train our nerve messengers and recorders also in the matter of colors. A little child is said to "see" only strong colors and not to discriminate between lighter shades. When we talk about this, we are going beyond the machinery of the body into the realm of mind; but as the eye is one of the machines most used by headquarters for the mind, the training of its messengers and managers to report accurately is very interesting and important.

WHEN YOU GO TO SLEEP

You keep your headquarters very busy all day long. Your cameras are all the time taking moving pictures, which must be recorded at the sight office; your sound receivers are kept on the alert all the time to report the air vibrations that come to your ears; your muscle engines are busy about their work at all places in the body; your heart pump is going rapidly; your lung bellows is working fast. Every single one of these activities means that messages are going to headquarters and being recorded, and that orders are going out. It is no small matter to keep the great body community working together harmoniously. Managing the blood supply alone is a gigantic task. When the stomach has received a meal, it must have an extra blood supply to keep its engines and its chemical factories at work. That means the brain will have less blood supply. Yet you will sometimes insist on doing hard brain-work just after you have eaten a heavy meal, and then will wonder why you feel dull and listless or why you have a headache. The headquarters offices do their best, but their workers are not made of iron and steel. They are living. Their own cell structure is wearing out under the strain. They are not having time to oil their machinery or repair waste. And the same thing is true of the busy muscle engines all over the body.

Then bedtime comes, and you stretch yourself comfortably on a soft bed. Instantly the muscles begin to relax. They need not work so hard. They will not be called on to produce motor energy. They will therefore throw off less heat energy. The rapid stream of messages which has been pouring in on the brain, with its corresponding set of messages to be sent out, is cut down to the lowest possible number. You have darkened the room; next you close your eyes. All the thousand and one messages to the brain from the eye cameras are shut off. You have opened the windows of your room so that there will be plenty of fresh air all night long. Thus the lung bellows will find it easy to get air with plenty of oxygen for the purifying of the blood.

During the day's activities there has not been time to get rid of the waste material which has been thrown off all over the body by the working cells. Sleep may come because of this accumulation, as we learned when we talked of the sleep of animals and human beings. (See page 255.) Now is the time to throw off those waste substances. Your going to sleep has given the opportunity. It has lowered the output of heat by requiring less work from the muscle engines. It has shut off the rush of messages to the brain headquarters. The heart pump has ceased to pump quite so fast; the supply of blood to the brain has been cut down. All the workers have time to rest and repair damages, to oil their machines and re-stoke them. The repair squads all over the body can go about their work without the interruption of constant messages from

headquarters. The food factories have a chance to catch up with their work with no new supplies being sent in to them from the outside and with all the blood supply they need. All the cleaning squads of the body are in possession, throwing out waste through the skin, or gathering it for disposal elsewhere.

You sleep comfortably for nine hours. When you awake, the body community will be in good condition again. All that was asked of you was to give the workers a chance, and to supply plenty of fresh air during the rest period. They are ready and eager to do your bidding for another active day.

WHEN YOU SPEAK

In the front offices of the brain where thought is originated comes the thought of the words you wish to say. With that part of the process we are not at this moment concerned. But it takes an army of well-trained workers to translate your thought into the words that will shortly come out of your mouth. The baby who is learning to walk has not learned to talk. He can make sounds, and he often makes the same sound every time he wishes a certain thing. But he has not learned our code of language. He has not learned to set in motion the muscles of mouth, throat, and chest so that they will set the air vibrating to produce the sounds which we call "speech."

The same current of air taken in for breathing is used, as was made plain in the diagram on page 335, to produce voice. In the larynx or voice box lie the vocal cords, which are controlled by delicately adjusted muscles. When these two cords, or elastic bands, are placed in a certain position, air driving past them will set them in motion. When the cords are drawn tight, a high musical sound comes from the voice box, for the cords are vibrating rapidly. When the cords are slackened, they vibrate more slowly, and a lower tone results. To speak loudly one blows a loud blast of air over them; to speak softly one sends a gentle current. The larger the voice box, the longer the vocal cords. The longer the vocal cords, the deeper the pitch of the voice. A young boy has the usual rather high child's voice; his voice box is small. As he grows his voice box will grow much larger, and he will come to have the lower-pitched voice of a man. This is after the same principle as that of the piano, in which the high notes are given out by the shorter strings, the low notes by the longer. The pitch of any string may be made higher by tightening it. When the voice box has stopped growing, the vocal cords cannot be lengthened and shortened; but their pitch *can* be varied by changing their tension. This is what happens in singing.

The vocal cords are the strings on which the air current plays. But a great deal more than mere voice production is necessary for speech. A violin string might be played upon with the utmost skill, but if it were not stretched above the carefully shaped air chamber of the body of the violin, it would not give out its beautiful musical notes. And even a violin string cannot talk! The vocal cords alone produce only weak and feeble sounds. These sounds are strengthened by the resonance, or sympathetic vibration, of the air in the throat and mouth. The singer depends on the lungs to admit and expel a good supply of air, on the vocal cords to vibrate according to the rate at which the air comes to them and at which their controlling muscles allow them to move, and on the cavities of the throat and mouth to intensify that note or sound as it passes through. In the mouth the movements of the soft palate, the tongue, the cheeks, and the lips may alter that sound so that it will emerge as speech. When you speak, a great many delicate adjustments are taking place. From the headquarters in the brain word is being sent to the muscles which control the vocal cords that these cords are no longer to lie flattened back against the walls of the larynx so that they do not vibrate at all. They are to be pulled together to produce sound. They are to be tightened or relaxed as headquarters directs. And as the sound passes through the chambers of the throat and mouth, the muscles of tongue, cheeks, and lips must be moved very rapidly in order that the sound from the voice box may be shaped into words made up of consonants and vowels. From the mouth air vibrations will go out and will set the outer air vibrating. You can catch with your own receiving machines those vibrations and can hear yourself speak. Other persons

can catch them with their receiving apparatus and can hear you speak.

The ability to hear yourself speak is not unimportant in the control of your speech. The same vibrations which you have been at such pains to teach your many engine drivers to produce will strike the drum of the ear and be received in the elaborate mechanism of the inner ear. Messengers are there waiting in the auditory nerve to carry this set of messages to the headquarters of hearing, where they are recorded. The busy messengers which run to and fro in the brain, carrying reports from one office to another, will give the message at the general headquarters. If your voice should sound to you too loud or too soft, word will be sent to the manager of the breath-controlling muscles to drive through less air; if the pitch is not right the engine drivers of the vocal cords may be notified to tighten or lengthen the strings. You may have noticed that the voice of a person who has been long deaf runs along on a level, monotonous tone. He cannot hear himself speak; so he cannot send these return orders which do so much to keep the machinery working well. A child who is born stone-deaf does not ever get, even with the most careful training, the same well-modulated speech that a hearing child acquires without conscious effort.

MEMORY RECORDS

This brings us to one section of headquarters of which we shall say only a word here,—the office where memory records are kept. The reports received in the upper parts of the brain are carefully stored away, and the ruler of the brain, the mind, is able to make use of them in carrying on the business of life. You can set your mouth and throat muscles to forming words which mean something to you and will mean something to those who hear them because of these memory offices in headquarters, and particularly that section of them where word memories are stored. If you are learning a French vocabulary, you say the words aloud over and over again, so that both the speaking of the words and the hearing them spoken will "fix" them, as you say, in your memory.

The messengers who come and go to all parts of the body carry on the ordinary routine of life. But the members of the great nerve army which dwell at headquarters in the upper parts of the brain, as indicated in the picture diagram of the head, have the peculiar ability "to 'hold up' messages which come to them, retain them indefinitely, and give them out again in future, if necessary, over and over. This storing of impulses constitutes memory." Memory changes the whole of life. The baby learns to walk, and from that time on he need not attend to walking except to direct when and how it shall occur, for there is a whole group of association memories at headquarters which will give to motor headquarters the necessary information as to what succession of movements is required. Habits come from associative memories. The oftener we do a thing, the easier it is to do it again. The plastic material of the brain might be compared to a wax cylinder for a phonograph. A brain record is made which can be used again, or, by another figure, a brain path is made which can be traveled again.

Language is a special sort of association. A certain code of sounds has been agreed upon by those who speak the English language as conveying certain ideas. Language is so closely connected with thought that if we followed the study of it a step further, we should be pulled over into the realm of mind, which is beyond the scope of a study of "The Machinery of Our Bodies." But it should be noticed here that when you speak you are using your sound-producing machinery as lower animals do not use it. You are drawing sharply the line which sets you apart as a human being with powers beyond those of any other living creature. In most of the lower animals the wax cylinder of the brain seems to be so soft that records of one day are erased or supplanted by records of following days. Actions are controlled chiefly by the lower departments of their brain or nervous system headquarters. With memory comes a change. When you remember, you think. When you think, you have come over into the realm of mind. The machinery of the body serves you, but you control it from a higher vantage point.

KEEPING THEM FIT

Photo by A. Tennyson Beals

WEIGHT AND HEIGHT AS TESTS FOR PROPER GROWTH

Child health is becoming a national as well as a family concern. Malnutrition or any irregularity in the working of the bodily machine can be most quickly detected by these two measurements.

THE FRUGAL MEAL.
From a painting by Joseph Israels.

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FOOD AND LIFE

Of your food business, and how to manage it.

IN the New England village of fifty years ago, the neighbors felt that they were bestowing high praise on a faithful husband and father, lately gone to his long rest, when they said of him, "He was always a good provider." So long as he lived this man had made it his business to keep his family well provided with food and the other necessities of daily life. He had not stinted his womenfolk and children, nor, we may be sure, had he been reckless or extravagant in his provision. His table had been set with the fruit of the land in its season. There had always been a generous supply. To be a good provider meant in the minds of the careful New Englanders to have looked well to the needs of the household, meeting them with intelligence, economy, a certain generosity, and a far-seeing regularity. It was the faithful continuance in well-doing, as well as its practice, which commanded their respect and earned their praise.

It is the business of each one of us to consider whether we are good providers in the management of the household of our own bodies. The chief business of every member of the great human family is the food business. Clothing and shelter are important but secondary. They can be attended to by special efforts which will carry over a considerable space of time. But the food needs are regular, insistent, and not to be denied. On the way in which they are met depends the well-being of each household. We demand a great deal of our bodies. We expect them to respond to our lightest wish. They meet our demands promptly and skillfully, asking in return that they be well nourished. Much has been learned within the last few years about what the body needs in the way of foods, and how it applies what it gets to its most varied needs. In this section we are going to give some of this new and fascinating knowledge of food in its relation to our lives.

Only when we try to picture a world without food or eating, do we have any idea of how many of our social customs and our everyday doings cluster about food. The painting of "The Frugal Meal" by Joseph Israels, reproduced on the opposite page, is put there to remind us how much of family life clusters

around the family table. However simple the repast, it is the magnet that draws the family together. The father and mother are the providers, the children receive from their hands, and in that circle of providing, sharing, and receiving the family tie is strengthened. The hen picking up the crumbs in this humble home calls to our minds the kinship of all living things in their need of food, and the dependence of the human family on the great kingdoms of lower animals and plants for the meeting of its food needs.

For a brief period, while they dwelt by themselves in the Wilderness for their instruction and discipline, the Children of Israel are said to have picked up twice daily the manna which fell from heaven. But when they returned to the life of the world, they were thrown back on the good old human way of tilling the land and gathering the harvests, of preparing their foods and exchanging them. If each man could go out and pick his food from some near-by tree, life would be simpler but it would have lost something. Even savage tribes gather for feasts, seeking the company of their own kind. The food needs of the world are the basis of human labor, human intercourse, trade, and industry. It is not a matter of each man for himself. If that state of affairs ever existed for a few Robinson Crusoes on their separate islands, it disappeared with the first families and tribes. Food is the great need and business of every human being; in this common need, they come together.

NATURE AS COOK

An easy key to food values: how are the foods made?

WHEN you take food as it is delivered at your kitchen door and cook it, you may think that you are giving it the first cooking it has ever received. You probably call it raw food, and imagine you are doing the whole business of preparing it. Not at all! It is Nature that takes the raw ingredients and puts them together into food. You are only adding the finishing touches. When you make a cake, your "raw materials" are flour, sugar, eggs, milk or water, and butter or some substitute, with a little of one thing or another added for flavoring or similar purposes. Nature worked a long time to get those materials ready for you. If you had to take really raw materials to make that cake, your ingredients would be carbon, oxygen, hydrogen, a little nitrogen, and so forth. Fortunately Nature attends to this first cooking for us.

Nature is very skillful in the enormous variety of dishes which it manages to concoct out of a very limited number of ingredients. Its whole cookbook would not have more than fifteen or so elements or ingredients. Chief among them would stand the familiar trio, — carbon, oxygen, and hydrogen. Nitrogen and sulphur would be found in another great group of foods, and phosphorus and iron would appear in other recipes. Sprinkled in, like pinches of salt or spices in our human concoctions, would be tiny portions of the other food ingredients.

If the ingredients in these recipes seemed queer to us, the system of measures would seem more unusual. Instead of teaspoonfuls and tablespoonfuls and cupfuls there would be atoms and molecules. Nature spells with the atom alphabet and writes its recipes in molecule words. Chemists have studied out and put in formulas great sections of this Nature cookbook which you will find interesting if some day you study the chemistry of foods. They are experimenting in their laboratories to see if they can cook as skillfully as Nature, and can turn out similar products. Sometimes they find they can, but it is usually a very expensive process. In general it is still better to let Nature do the work, only giving such aid as is needed to provide the right supplies when they are lacking. The farmer who puts fertilizer on his soil is supplying nitrogen for some products which he wants Nature to turn out.

READING NATURE'S COOKBOOK

Since you and I are very willing to receive from Nature's bounty, we can accept Nature's

foods as they are, peering into the pages of this complicated cookbook only long enough to see of what in general these foods are made, and to what uses they can therefore be best put. The chemist will tell us that he finds that the greater part of these recipes fall into three groups, — the carbohydrates, which are made from carbon, hydrogen, and oxygen; the fats, which are made from the same elements in different proportions; and the proteins, which have at least two other ingredients, nitrogen and sulphur, and sometimes phosphorus or iron. There we can dismiss that matter except to add one fact which will show us on what a huge scale this cooking must go on to supply our human needs. Here is the chemist's record of what we citizens of the United States eat every day, given in the terms of these ingredients as thus grouped. "Per day," he says, "the population of the United States consumes 2,000 tons of nitrogen in the form of protein (equivalent to about 50,000 tons of protein foodstuffs), 6,500 tons of fats, and 50,000 tons of carbohydrate material." Very much of this enormous quantity of food is fortunately produced within the boundaries of the United States. When we make gardens and keep hens and tend cows and fatten pigs and raise beef, we are almost tempted to think that we are creating this food. We must never allow ourselves to forget that our share is mostly in the line of giving Nature the chance to do a great deal more.

WHERE DOES NATURE GET ITS INGREDIENTS?

Air and water should supply the four chief elements if this proved to be the best source for them. Water provides hydrogen and oxygen; air has the carbon, though in the smallest quantities. Here Nature can call in the cheapest of laborers, the plants, and put them at work setting their traps with the magic chlorophyll for the capture of carbon. Man would be helpless before the problem of getting enough carbon from the air. He finds it very difficult to get nitrogen, though the air is four-fifths composed of it. It is curious to think that man lives in an ocean of free nitrogen; yet it is so free that he cannot capture and "fix" it. Again Nature does the trick quietly and without any fuss. On the roots of certain plants — clover, cowpeas, and others of that type — swarm thousands of bacteria, so small it takes a microscope to get a view of them. They take nitrogen from the air, combine it with other elements, and feed it to the plants. The four chief ingredients of Nature's recipes are thus accounted for; the rest are in combination in the soil of the earth, or are thrown off in some of Nature's chemical processes.

HOW DOES NATURE DO ITS COOKING?

How does Nature cook its dishes? By heat energy. And where does the heat energy come from? Chiefly, from the sun, that great storehouse of energy on which the earth draws unceasingly. When you read the title of this chapter, "Nature as Cook," it may have seemed to you fanciful. Perhaps you thought to yourself that Nature did not really cook. Let us consider the matter and see if Nature's work is not really very much like what we call cooking. The dictionary says that cooking is "preparing or treating anything by the action of heat, especially to make it suitable for eating." Sunlight falls on a tiny pot holding a living fluid, and by the energy of heat the fluid in that pot is brought one step nearer the stage when it will be ready for eating. Is not that cooking?

In the cell pots of plants Nature prepares a great supply of the carbon-hydrogen-oxygen compounds known as "sugars and starches." The potato is a familiar example of a starch; maple syrup, or the liquid from sugar cane, used as the basis for our white sugar, illustrates the sugar foods. Another group of foods, the "fats and oils," are cooked in some plant cells and in more animal cells. They are made of the same three ingredients put together by a slightly different kind of recipe from that of the other carbon-oxygen-hydrogen products, the sugars and starches. In the plants that take nitrogen from the air, there is naturally the addition of nitrogen to the food product. They take on the name given by the chemist to another great group of Nature foods, the "proteins," which are made by much more complicated recipes than the two basal groups

Courtesy of American Museum of Natural History New York

A DISH OF PRUNES AS ANALYZED BY THE CHEMIST FOR FOOD CONSTITUENTS

Each test tube shows the proportion of its respective ingredient found in the prunes. P, protein; C, carbohydrate; F, fat; W, water; A, ash (mineral matter); R, refuse.

which we have already mentioned, and are put together in both plant and animal cells. It is important that Nature does prepare all these kinds of foods by cooking, or by the use of heat energy, for man and the animals wish to use them as fuel foods — and that is the next story.

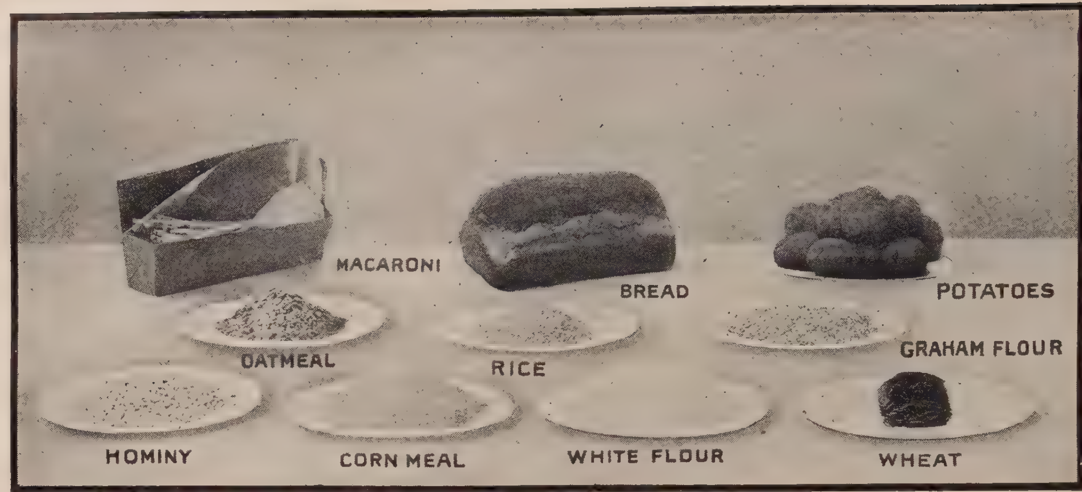
FOOD AS FUEL

It is a new idea to measure food as fuel. If a furnace needs a certain amount of fuel to produce a certain necessary amount of heat, it is well to test what you are supplying to that furnace and see how much good fuel there is in it. The problem is how to do it. Twentieth-century food specialists have invented a piece of machinery by which they do this. They call it a "calorimeter," which means simply a "heat measure." *Thermo*meter comes from the Latin word for heat; *calori*meter, from the Greek word for heat. By this instrument they measure heat in units called "calories." There seems to be no need for us to concern ourselves much with the way these heat tests are made. This work has been done in the laboratories. We are given the results in a form convenient for our use. When you read on your menus, as you might in a whole chain of restaurants in New York City, or when you see in advertisements or in cook-books that such and such a food supplies so many calories, you want to know what is meant. You are simply being given the value of that food as a fuel.

Back in the days of Columbus or a little later there was a Swiss physician by the name of Paracelsus who was very much interested in the machinery of his body. He puzzled and puzzled over what could be happening to the jumble of foods which he took into his body every day, and he finally hit upon the quaint idea that there was in the stomach a presiding spirit which watched the food as it arrived from the mouth and sorted out the good food from the bad. The good food, such as was desirable for the body, he sent on its way; the bad food, which would be of no particular use, was dispatched as waste. If a Paracelsus spirit were sitting within us watching the food which you and I dispatch into our bodies, there would be one thing he would be looking out for eagerly in every meal. That would be to see if we were sending along a sufficient amount of fuel to keep the body engines going. He would know that you as master of the body would require a certain amount of heat energy and movement energy and that you would expect him as chief food manager and engineer to provide it.

Since you do require this of your food manager, it is only fair to supply him with the right amount of fuel. That is where the twentieth-century food specialist has taken a hand. Since the days of Paracelsus physicians have learned many things. With their food thermometer they can test food *before* it goes into the body, so that they have a fairly accurate idea of just how much energy it will supply in the forms of mechanical work and heat in the cell engines. They will tell you the fuel value of a lump of sugar, a doughnut, a piece of bread. With the same kind of food thermometer they have been able to measure the heat which is used in all the engines of the body community as they work together. They know how much heat energy a man expends by the hour when he is asleep, when he is awake but lying still, when he is walking, running, sawing wood, or painting a house. They have gotten it down to such a fine point that they balance the two and tell you that three lumps of sugar will furnish enough extra energy to enable a man to walk a mile.

These facts are very interesting, as we shall see when we apply them to some of our daily meals. But most of us feel that we cannot go around with a heat measure in our hands or a fuel table in our minds. We cannot be always eating by calories. Yet it is obvious that if the body machine requires fuel and it is our responsibility to provide it, we must not wholly ignore the matter. Happily for us, there is a very simple way to test our foods that every one of us can practice with ease. As much heat can be gotten out of a food as has been put into it. Nature does the "cooking"; the "burning" takes place in the human body. If we lay aside the food tables for a while and go out and look at the world of life about us, watching to see how Nature prepares food in its great kitchens, we shall be able to come back to our own kitchens and our own tables with a fairly clear idea of food values, both for fuel and for other needs.



STARCHES—STORED FOODS

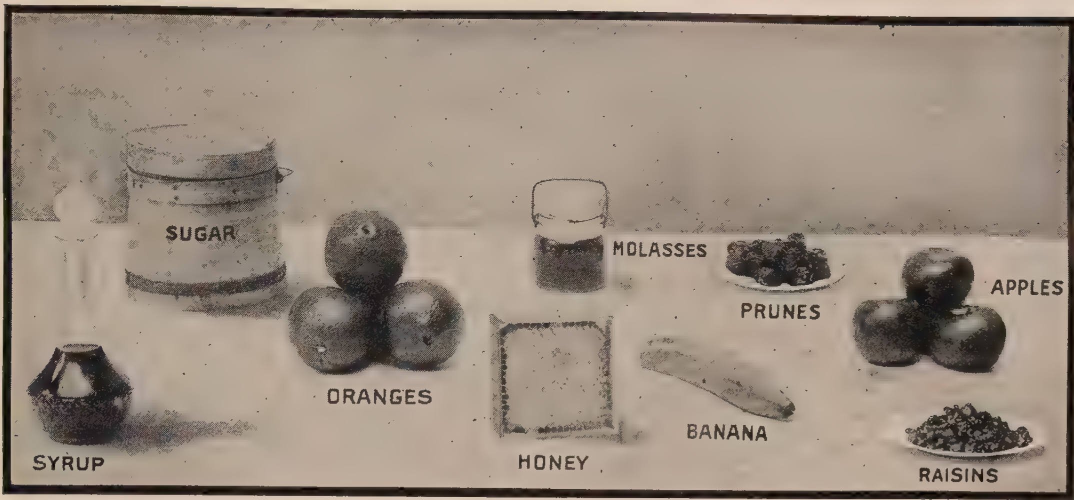
STARCHES are stored foods. When a plant wants to store away food for its own future use or for the use of its seed children, it packs it away in the form of starch.

When in those long-ago times plants and animals stood at the parting of the ways and plants chose to stay still, they committed themselves at once to a business of storing energy. That was the benefit of the manner of life they had chosen. They could take the sun energy which was pouring in on them and put it in a storehouse for the use of themselves and their children in the days when it might be needed. They reached out into the air about them and down into the ground beneath them for their ingredients, and turned their tiny cell mixing pots into a great kitchen for preparing food. When it was first cooked this food had a great deal of water in it. Water, besides taking up space, has no fuel value. As they packed away this cooked food in their stems and seeds and roots, they let the water out. Wherever you and I find solid food stored away in this fashion, we shall find good fuel foods, foods into the preparing of which went much heat energy.

Look at the foods in the picture which heads this page. They are all stored foods. The potato is the storeroom of the potato vine. A goodly supply of starch has been packed away here for the sprouts (which are to come from the eyes of the potato) to live on until they have grown big enough and strong enough to capture energy from the sun for themselves. The other foods here grouped all come from the cereal plants in which starch is stored in the seeds. Oatmeal is a meal made from the grain or seed of the cereal grass, oats; rice is from the grain or seed of the cereal grass, rice, which grows in warm climates and is the staple food of certain Oriental peoples; corn meal and hominy are from the Indian corn or maize which our fathers found in cultivation when they landed on these shores; wheat, graham flour, white flour, bread, and macaroni are all products prepared from grains, macaroni being a paste composed chiefly of wheat flour dried in long slender tubes for cooking. These are the inexpensive fuel foods that give bulk to the diet.

Animals eat raw starch; the herbivorous animals like the horse and the cow make it a chief part of their diet. But it is quite a matter to digest it. In the cow and other animals which chew their cud, there is a second chance for the chewing of it, as well as sometimes a second stomach for digesting it. Human beings find it much easier to digest after they have cooked it. This is one of the cases where we supplement the cooking which Nature has given it by our own cooking.

When you see a plant food in which the plant has stored away starch for its own use and that of its seed children, then you will know without going to any book that here is a good fuel food.



SUGARS—PREPARED FOODS

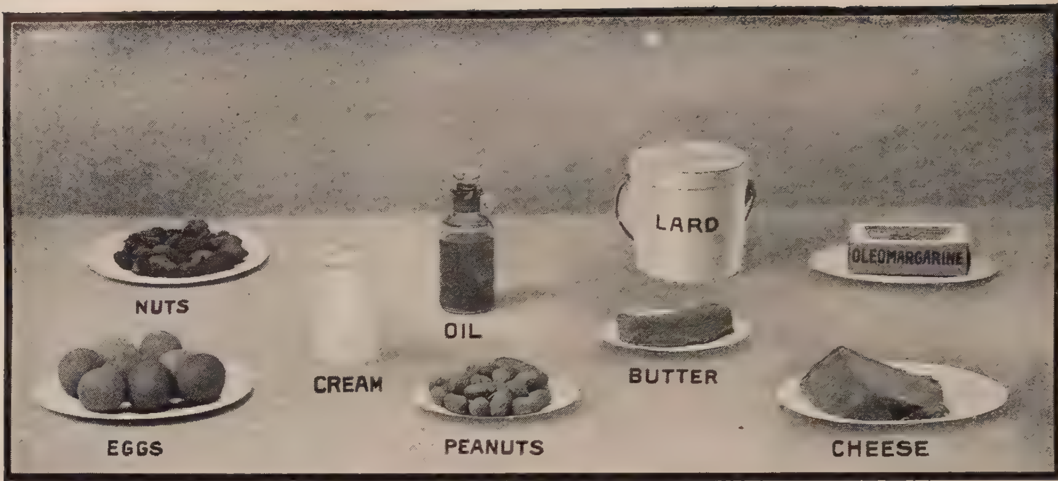
SUGARS are handy, convenient fuel foods. They are found in all plant sap and in plant and fruit juices. One might almost say of them that they are foods in transit. Their make-up is very much like that of starch, and starch is changed over into a sugar very easily. It has to be, for starch cannot be easily transported. It cannot be dissolved in water, and the whole transportation system of plants and animals is a water system. Sugars can be dissolved in water. So by a convenient sleight of hand and the application of a little energy, Nature changes its starches over into sugars and dispatches them on their way. In the form of sugars they are delivered as food fuel at the walls of the hungry cells; in the form of sugars they are delivered as building materials for the walls of plant cells; and if in the economy of the plant some of this food can be spared from present use and stored as a reserve food, it will very probably be turned promptly back to starch. Sugars are prepared foods, traveling about in the forms most easily put to use. When some of the water is drained from them, they are very valuable as fuel for the human body.

Our prepared sugar which comes to our table in crystals is a pure fuel food. It has no water and no waste. It has been made either from the watery juice of the sugar cane or from the juices of the sugar beet. Molasses is a sweet liquid drained from sugar in the process of its manufacture. Maple syrup comes by evaporating the sap from the sugar maple tree. Corn syrup comes from the starch of the corn, being made into sugar by a chemical process. When you eat honey, you are eating the reserve food which the bee has stored away as you might have put money in the bank.

Fruits are largely composed of water. Their juices contain sugar, which gives them a pleasant flavor and some slight fuel value. When the water is evaporated out of them, as it is in raisins and prunes, they have a high fuel value.

Sugars, and especially our white granulated sugar, are an excellent source of fuel when taken in small quantities. Three or four lumps of sugar will give as much fuel value as a good helping of some other foods. It is so perfect and so pure a fuel that man cannot live on it. A man could starve on sugar, for it has no other contribution to make to the body besides its fuel value. Too much sugar piled in on furnaces already well supplied with other fuel will choke them. The body manager will try to protect the cells from this excess by storing it in the shape of fat. Nature dilutes its sugar with water and offers it to the cells only in small quantities. We do well to follow its example.

When you want a quick, pleasant-tasting, easily digested fuel food, take a little sugar, but do not overfeed your furnaces with it. Take some of your sugar in fruits and you will get other good things with it.



FATS AND OILS—CONCENTRATED FOODS

FATS are Nature's concentrated fuel foods. Weight for weight, a small cube of fat or a drop of oil will give two and a quarter times as much fuel value as the same weight of any sugar or starch. "Fats are fuel for fighters," wrote Uncle Sam on a government poster which was widely distributed during the war. Being concentrated, they were therefore easily carried.

Fats are made from the same three ingredients that are used in sugars and starches, but there is less oxygen. That is why they are better fuels. They can take up more oxygen in proportion to their size and therefore burn more hotly. The recipes for fats are all very similar; the products may appear either in solid or in liquid form. It is only for convenience that we speak of them as fats and oils.

We began with very simple dishes produced in Nature's plant kitchen, the starches and the sugars. Fats are more complicated and are more likely to be cooked in animal kitchens. Fats are produced in some plants. As one would expect of so concentrated a fuel, they are stored as reserve food in seeds. Peanuts are forty per cent fat, pecan nuts seventy per cent. Peanut butter has a very high fuel value because of its almost solid fat. If we had been showing prepared foods in the group above, a cup of cocoa or a bar of chocolate would have been included. Both gain their fuel value from the oil in the cacao seed from which they are made. The castor-oil bean, the soy bean, cottonseed, and flaxseed are other oil-bearing seeds. The olive is grown largely for its oil.

Fat is used chiefly for fuel. In the animal as in the plant any excess of the amount needed for fuel is stored away as body fat. We need a certain amount of body fat as a reserve. It is a poor conductor of heat and therefore keeps the body warm by keeping its heat within it. In case the body machine runs short of fuel during illness or in cold weather or in violent exercise, it is good to have this fat set away in the storehouse for use. But too much fat is a burden on the body.

The yolk of an egg is one-third fat. Cream, butter, and cheese are dairy fats. Oil may be a vegetable oil or an animal oil. Lard is animal fat, though our commercial lards are often softened with vegetable oils. Oleomargarine is made by churning different fats with milk, usually vegetable or nut fats. All fats have the same fuel value. They would all taste, smell, and look alike were it not for minute quantities of other substances (not fats at all) which change them slightly. They are too concentrated to be eaten alone. They add much to the pleasure of the diet, a small amount of some fat being almost necessary for palatable cooking and serving according to our ideas.

A limited amount of fat is good for us; an excess of fat is heat-producing and adds a burden to the body if it is stored in reserve.

LIFE FOODS

FUEL foods a man needs because his body is a machine. It must take in energy in order to give it out. Life foods he needs because his body is a living machine. It is always building, rebuilding, repairing, oiling, and self-regulating itself. It is because it is living that it can stand so much. Iron and steel would wear out under the strain you put upon your body. When a train is to make a long, very fast run, engines are changed because the parts cannot stand the continuous strain. They must be put into the shop to cool down, be re-oiled, and have worn parts repaired.

Because your body is alive, it can act as its own repair shop. As its parts wear out under the constant strain, it can renew them. As they need repair it can rebuild them. It can oil itself and keep itself running smoothly and silently without any of the distressing creaks and groans that come from unlubricated machinery. Because your body is alive, it built itself. When you were born you had only a small body. Year by year it has grown to its present size. Perhaps it is going to grow some more. All this growing has been managed while you were using it right along. There is nothing in all the world so wonderful as this living, growing, self-repairing, self-regulating machine.

To accomplish all this your body must have foods. Like any other builder it must have materials to work with. It must have lubricating oils to keep the machinery running smoothly. It must have a free flow of water to wash off the parts and carry away waste. These materials come to it in the food. The foods which do all these things we are choosing to call "life foods." We might almost call them "body foods," for they go toward the building and maintenance of the body instead of being burned as fuel. But they are more than body foods; they have had the magic touch of life.

We have seen how Nature uses heat in preparing its foods and finds it as necessary as we find it for the dishes we serve on our tables. But more than heat is needed. The chemist can take some of the same ingredients — gases and minerals — which Nature uses and treat them with heat and turn out a very fair product. But he cannot turn out a living seed or produce a living, growing machine. They are still common elements until Nature gives them the magic touch of life. We cannot see how the living cell differs from the dead cell; but that it does differ we know. Somehow that very intricate combination of atom and molecule words has had life written into it.

This much we do find out: Wherever life is, there is found the kind of fluid we have named "protoplasm" or "first stuff." It is evidently life's mixture. When we come upon it, we are next to life. If you took some pages of Nature's cookbook as the chemist has written them down and copied out the fifteen ingredients found in foods, and then were to take a physiology which gave the elements out of which the human body was built up and listed them, you would find the two lists were identical. Naturally it would be so, when we stop to think about it, for the body builds and rebuilds itself out of the food which it receives.

Courtesy of the Shattuck Farms, Andover, Mass.

TWIN BROTHERS, FOUR MONTHS OLD

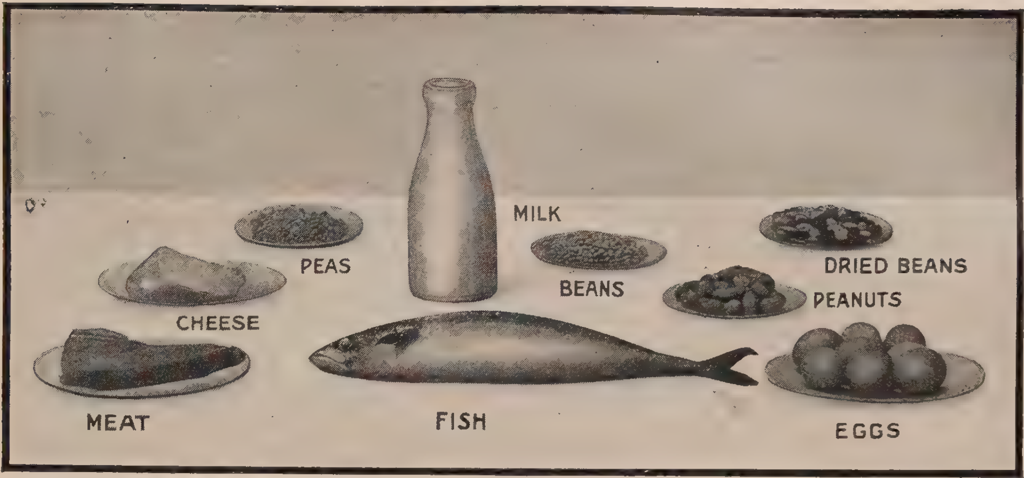
But the larger one lived on a milk diet, while the smaller took no milk. At the age of four months the smaller began to take milk, and at eight months the twins were the same size and could hardly be told apart.

When we examine plants and animals and find that their living cells are filled with this same life fluid with which the body cells are filled, we are led to think that the best thing we can do for the body to help it in building and repairing its cells is to give it foods which have a great deal of this life-stuff. All foods which have been alive have more or less of this mixture. The nearer we come to the life of the plant or animal and the closer we get to its living part, the richer the food is in this life-stuff.

So again we say to you that you may let the lists of body-building and body-repairing and body-lubricating foods in the diet lists and the cookbooks wait for a little, while you go once more into Nature's kitchens and see what parts and what kinds of its foods come nearest to the life of the plant or animal in which they are found. Where life has been in the plant or animal, there is the life-stuff which will be the best material for your living machine in keeping itself going. No food is all a "life food" any more than any food is all a "fuel food." Nature's cookbook does not have its recipes labelled "Life Food No. 1," or "Fuel Food No. 6." Nature is not running a chemistry laboratory; it is running a food shop. It is providing the necessary mixtures for carrying on all the life processes of its living plant and animal and human machines. So like the good cook it is, it mixes them up into appetizing dishes. Into some it puts more fuel foods; that is when the food is to be stored away as a reserve, like money in the bank, to be drawn out in case of need. Into others it puts more life foods; that is in the parts where there is going to be the most life and growth. Because animals move about more and are more alive than plants, they are likely to have more life foods than their quieter neighbors. But plants will have life foods in the parts which are most alive.

THE DAIRY COW, THE BEST FOOD FACTORY IN THE WORLD

A cow weighing one thousand pounds and yielding five thousand pounds of milk per year is producing five times her own weight in a food all of which is digestible.



PROTEINS—FOODS NEXT TO LIFE

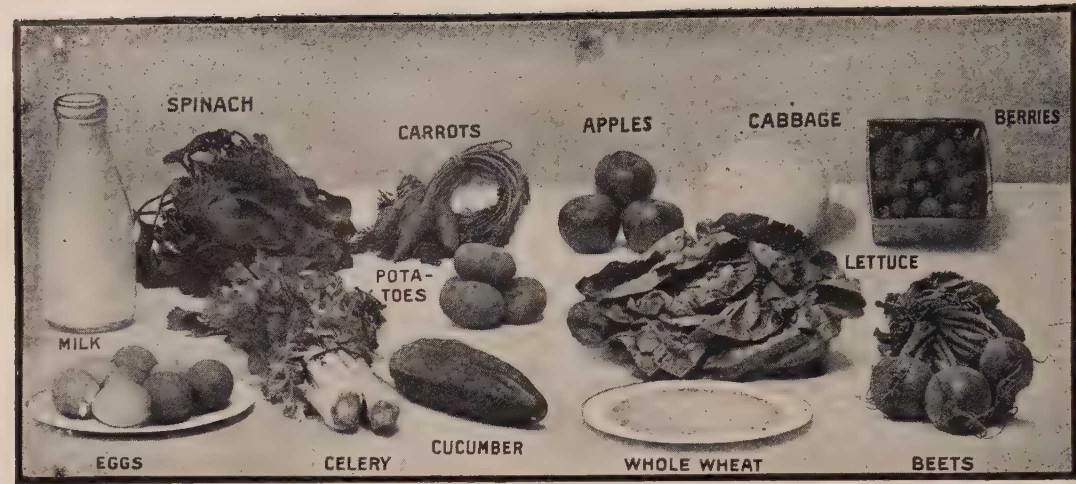
THESE are "first foods," so named from the Greek word *protos*, meaning "first." They are the compounds cooked in Nature's kitchen which receive the magic touch of life and turn into the wonderful life-fluid called "protoplasm," or "first stuff."

All proteins are not alike. There is a verse in the Bible that reads, "All flesh is not the same flesh: but there is one kind of flesh of men, another flesh of beasts, another of fishes, and another of birds." So also there is a flesh of green leaves and another of seeds and another of milk and another of eggs, and so on indefinitely. Nature does not fashion its living creation after one recipe. It takes most elaborate molecule words, built up of atoms grouped in hundreds, and out of them it writes protein recipes. By the touch of life they are made still more individual and separate. With fuel foods it is a matter of taste and of convenience which one we shall eat. One fat gives as much fuel as another; starch is starch wherever it is found, and the different sugars differ only in fuel value, not in kinds. But proteins do differ. It used to be the idea that one kind of life food was as good as another, and that there was no gain in eating a dozen, except in the matter of pleasure and taste. Now it is known that it does make a difference. All the proteins, whether of fish, flesh, or fowl, green leaves, or seeds, are good for us; but the different proteins found in these different kinds of "flesh" do each a special work in our bodies. The way to get enough of protein in general, and of all the different proteins which will be good for you, is to eat a good variety of meat and fish and seed vegetables, with milk and eggs.

You will not be surprised to see some of the same foods appear in these pictures two and three or more times. They are so arranged that life foods and fuel foods are all mixed in together in good, healthy measure. Meat and fish appear for the first time in this group. They are especially good as protein life foods. Peas and green beans and dried beans and peanuts are all seed vegetables. The germ of life is within them, packed, to be sure, in a good coating of stored fuel food on which the growing plant may feed, but it is there just the same, and when we eat them we get the benefit of it. Cheese is here because it is made from the protein part of milk. Milk and eggs are the most perfect all-round foods. A pint of milk has a half-ounce of a very valuable protein, an egg is about twelve per cent protein.

Protein can be burned as fuel food, but it is an expensive fuel food and its waste products after burning, or "ashes," are of a kind that clog the body machine. Proteins never last over; they are disposed of as received.

To eat too much protein food is wasteful, for if it is not needed as a life food, it will be burned as a fuel food. A variety of proteins gives a safe, well-balanced, body-building diet.



MINERALS AND WATER

IT will be no hardship to eat the vegetables, fruits, and other foods suggested in this group. They will taste good; they will also surely do you good. They will supply water, which is so important as a common carrier and as a part of the contents of every living cell, and mineral matter, which the body must have.

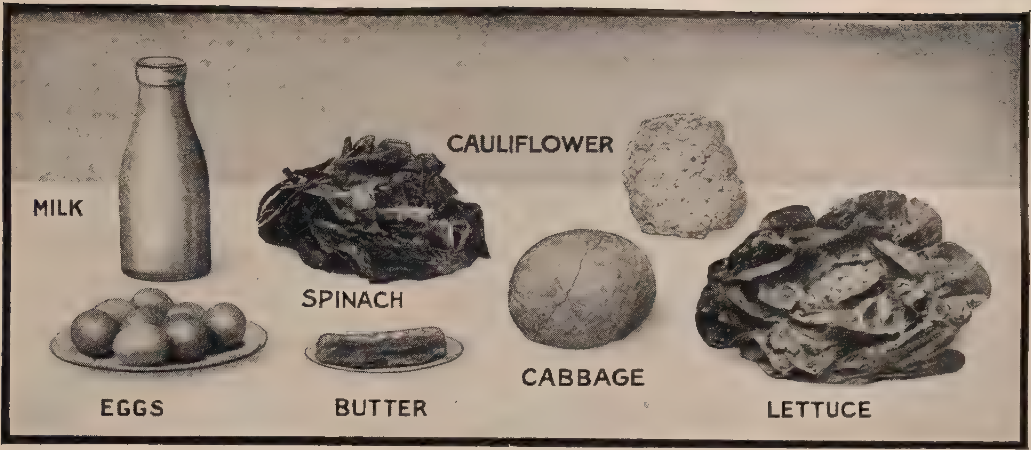
Salt is the only mineral which you eat separately and consciously. But there are others which are equally important. Some of them are used as building materials, others act in the blood and other liquids to keep the body machinery running and the proper chemical action taking place. For instance, every red corpuscle must have its infinitesimal bit of iron. If it does not, it will grow pale and will not take in as much oxygen as it should. Hemoglobin is a protein, — globin, with an iron-carrying colored substance. Iron is found in milk and eggs. The most important sources are, however, vegetables and fruits, which should be eaten, especially by children, in generous measure. It is also present in whole wheat and other grain products which have not lost it in the milling and making into flour.

Every one of the foods shown in the group at the head of the page is rich in other minerals which are needed in the body building. It is hard for us to realize the great changes that are taking place daily in our bodies. Tissues are being torn down and new tissues are being built up. Our bodies are not all of soft flesh. There are cell walls which are thicker than their liquid contents; there are bones which make up the framework for the body; there are teeth and finger nails and other specialized parts of the body. All these must be constantly built anew. For a growing child they must be built rapidly. Calcium (lime) is a bone builder. We find it in our milk and also in leafy vegetables and other foods shown here. It takes a little magnesium to build bones and muscles. Potassium helps out in the soft tissues of the body. And so we might continue through the list of mineral and inorganic (without life) elements present in the body and therefore needed in food. Acids and alkalis, salts and phosphates and chlorides and other compounds, all take their part in keeping the balance right in the body fluids and the action right in all the processes.

Water is absolutely necessary. Fruits and vegetables are mostly water, pleasantly flavored by these other constituents we have mentioned. It is healthy to get a good deal of our water this way.

Fruits, vegetables, and whole wheat foods all give bulk to the food. This is not only pleasant but essential. To work well, the food factories must have a good mass of material to work on. Without them they would get soft and flabby.

For pleasant variety, for mineral elements, for water, for bulk, eat these foods.



VITAMINES—FOR GROWTH AND HEALTH

THE same foods—eggs and milk and butter, fresh and leafy vegetables — here they are again. What for now? That is what the chemist said when he tried to take a hand as cook and helper in Nature's food business. He took all the necessary ingredients. He reckoned how many calories were needed for fuel food, how much protein for body building, how much water and mineral matter. He shifted them around and made a diet; but he left out some things that were in the diet Nature ordinarily supplies. He left out some of the very things shown on this page and put in substitutes for them, which would seem to have the same ingredients. And the diet did not work! The pigeons or the rats or the guinea pigs or the cows that he fed on it did not grow well or did not flourish in good health as they should. Then he gave a little of some one of Nature's special life foods. To his chemically perfect, carefully cooked, germ-free diet he added some of the fresh uncooked milk on which Nature feeds its young and growing animal and human children; he gave fresh green-leaf foods, like spinach or lettuce or cabbage or cauliflower; he gave grains straight from the harvesting; in short, he gave foods that were very much alive or were the very recent, fresh product of life. And his young, growing animals, which had stopped growing and become sick on his chemically perfect diet, responded as a child does to its mother's touch and ate with avidity and ran about and grew and flourished. The chemist had learned a great deal about Nature's recipes and Nature's method of cooking, but he had not learned it all. Nature had still some tricks in making its living stuff that he could not yet match. So the chemist went to work again, and he found out about some mysterious substances which he has called "vitamines," "life foods," from the Latin word *vita*, "life." He is still finding out about them, but this is the story so far as it can be told now:

It began with pigeons and rice. People who lived on rice in Oriental countries had a disease called beri-beri, which came to them and to them alone. Pigeons were fed on rice and water; they fell ill of beri-beri and soon died. The rice used was the polished or milled rice from which the hulls had been removed. Then they were given raw, unhulled rice, and they recovered and lived well and happy ever after. We know that there was a vitamine in the outer hull of rice which they needed. This particular vitamine (called by the scientists, in order to identify it conveniently, Vitamine B, or Water Soluble B), which was proved to be necessary for growth and health in all animals and in human beings, is found in the outer hull of grains, in their germs, in green leaves, in fruits, in beans, and in yeast. Skin diseases which came from not having enough to eat are often cured by injecting fresh yeast. That was one vitamine, located by the experiment

made on pigeons with rice. Now any one who shows a tendency to beri-beri eats whole rice and all is well.

Meanwhile rats in a food scientist's laboratory failed to grow on a proper, chemically perfect diet of foods, until he gave them a thimbleful of fresh cow's milk a day, whereupon they, too, flourished and multiplied as rats should. They needed Vitamine A (or Fat Soluble A), which is found in milk, cream, butter, cod-liver oil, and green vegetables. Sailors going on long voyages in the old sailing vessels suffered seriously from scurvy. They lacked Vitamine C (or Water Soluble C), which is found in oranges, lemons, limes, and in tomatoes, cabbage, and lettuce, as well as in a few other fruits and vegetables. Sailors had no fresh fruit or vegetables. Other vitamines, similarly named, have been identified in familiar foods as essential or desirable for a balanced diet.

This story of vitamines only brings us a little closer to Nature.

Once more we are reminded to eat fresh fruits and vegetables, eggs, and milk—all good life foods.

THE DAILY RATION PLAN

The price man pays for freedom, and the measure of his independence.

MAN lives on a daily ration plan. His body machine needs a daily water supply, a daily fuel supply, and a daily body-building and body-repairing supply. The water supply he must have. Men who are undergoing long fasts are given a water ration each day. The fuel supply he should take. A man of average weight and activity is expending twenty-five hundred to three thousand calories a day in energy. It is good business for him to provide an equivalent in fuel. If he does not, he will draw on his body stores of starches and fats. A person who is undergoing a long fast is practically turning cannibal; he is living on his body. Life foods he should have. The proteins cannot be stored in any quantities, as can the carbohydrates. They pass into the body, their needed portions are used, excesses are burned, and they pass out as waste. To fail to provide them is to consent to a weakening of the bodily machine. In a long fast the body weakens and wears out. But on the daily ration plan all these needs are attended to, and the body machine does its work so smoothly, easily, and efficiently that we are hardly conscious of it.

THE PRICE OF FREE MOVEMENT

The daily ration is the price man pays for his freedom. He spends his energy without reserve in movement and activity. No vegetable existence by which he would remain quietly rooted in one spot for him! He belongs at the head of that animal group which took the great risk of spending energy as they went along instead of storing it. It was a risk, but like most adventures it brought its own reward, and to man the greatest rewards of all, for he has acquired the greatest freedom. He counts providing of three meals a day a small price to pay for the freedom of movement which he enjoys.

HOW THE ANIMALS MANAGE

Man does not even store food as some of the animals do. The camel lives off its hump in the long journeys across the desert; the fat-tailed sheep stores an abundant larder in its tail against the time of need. Hibernating animals which require a daily ration for all the working periods of their lives take long winter sleeps in which they keep the flame of life burning at its lowest possible point of safety and draw such supplies as they need from their well-stored bodies. How fat some of them are when they go into winter quarters and how lean and hungry when they come sleepily out in the spring! It takes a good deal of instinctive wisdom to prepare for the winter sleep and to get back into good physical trim after it again. A bear has a big stomach and feeds on small things,—ants, berries, and vegetable foods. He appears to be always hungry. When

FRESH FROM THE GARDEN

GREEN VEGETABLES FOR GOOD HEALTH

Countless experiments have demonstrated that nothing can take the place of "green things growing" in our food. They are life foods which supply needed elements for body building and body regulating.

the first snow falls he begins to get ready to go into winter quarters. He goes into training as an athlete would. Sudden changes are disastrous to any bodily machine; so he begins to cut his rations down, eating less every day. Meanwhile he drags pine boughs and fallen leaves into his den to make a soft bed, fills up the crevices where cold air might come in, and blocks the entrance. Two or three weeks later, when the big snow comes, his intestinal food factories are practically empty. He crawls into his den and goes to sleep. His blood rate, his heartbeat, his breathing are all slowed down almost to nothing. There is little demand made on his muscle engines or nerve headquarters. The winter passes. A new supply of vegetable food grows. After a sleep of two or three or four months he comes out. His living food factories are weak from disuse. He treats himself as the nurse treats a convalescent. He eats carefully so as not to strain the flabby parts; at night he returns to his den to sleep. Under this careful use all the machinery begins to take on tone. In ten days or two weeks he is all right again and takes up his regular habits.

Birds are of all living creatures the most active; in proportion to their size they exhibit the greatest amount of energy. The wings of a humming bird vibrate so rapidly that they can scarcely be seen, making only a moving blur in the air. "Great wheels," it has been said, "chained to roaring waterfalls and belted to smaller wheels, which in turn move giant gangway saws or huge millstones, scarcely produce an amount of power that will cause more rapid motion." The bird's freedom of movement, like man's, depends on frequent intake of food. If you watch a bird eat you will be surprised at the amount of food which it swallows and the rapidity with which it takes it. The bird has two special contrivances to take care of this hastily gulped food. It has a crop which is a sort of half-way reservoir where the food can be stored until the stomach is ready, and its stomach is in two parts, a stomach like that of other animals and a gizzard. There is also an excellent sewage system by which waste is passed along rapidly to make room for new food. There is hardly any storage system. The bird takes in food rapidly, frequently, and in large quantities; it digests it rapidly and thoroughly; it throws off waste material quickly. It earns its swiftness of movement and its energy by attention to its food supply.

HOW MAN IS HELD TO THE LAND

Man is limited in his possibilities by the daily ration plan. It holds him to the land as firmly as a string holds a kite to its mooring. He must keep within reach of food. When

Photo by Wm. L. and Irene Finley

SNOWY OWL

A bird requires a large intake of food to match its tireless output of energy.

boys go camping in the woods they must take food supplies with them. The ship bearing its human freight across the ocean must have sufficient food to last out the voyage. The daily ration has always made the problem of exploring parties. Peary could discover the north pole because he had learned by twenty years of experience how to keep his men supplied with a healthful arctic ration which they could carry with them. The intense cold and the violent exertion of arctic travel make for the burning of a tremendous amount of fuel in the body engines. Yet every ounce of weight burdened his men and took from their strength. He studied the matter to get the best and most

Courtesy of American Museum of Natural History

A SAMPLE BREAKFAST SUITABLE FOR A SCHOOL CHILD

1 cup of oatmeal, 2 slices of toast, 1 tablespoonful of butter, 3/5 of a cup of cocoa, 1 baked apple with sugar, and 2/3 of a cup of milk. This sample breakfast represents a heat value of 600 calories; it contains 15.76 grams of protein and the necessary amounts of iron, phosphorus, and calcium.

nourishing food into the smallest space with the least weight. These were the results:

"The essentials, and the only essentials, needed in a serious arctic journey, no matter what the season, the temperature, or the duration of the journey, whether one month or six, are four—pemmican, tea, ship's biscuit, condensed milk. Pemmican is a prepared and condensed food, made from beef, fat, and dried fruits. It may be regarded as the most complete and satisfying of all meat foods. . . . The standard daily ration for work on the final sledge journey toward the pole was one pound of pemmican, one pound of ship's biscuit, four ounces of condensed milk, one-half ounce of compressed tea, and six ounces of liquid fuel (alcohol or petroleum). . . . On this ration," concludes Peary, "a man can work hard and keep in good condition in the lowest temperatures for a very long time." This made a total of two pounds, four and a half ounces of solids for each man daily.

It is not an attractive ration. We should be sorry to adopt it. To be taken away from the fertile land which will furnish fresh milk and eggs, fresh fruits and vegetables, and to have to eat food so condensed into small portions would be a physical and a mental hardship.

Courtesy of American Museum of Natural History

A SAMPLE MENU FOR A CHILD'S MIDDAY DINNER

1½ ounces of lamb (stew), 1 medium-sized potato, 1 cup of cooked spinach, 2 slices of whole wheat bread, 1 tablespoonful of butter, 1 cup of milk, and ½ cup of rice pudding. The portions also separately represent a heat value of 100 calories each, except the spinach, milk, and rice pudding, which supply 50, 150, and 200 calories respectively.

Yet it can be done for short periods, and by thus rationing themselves this gallant band was able to gain a long-sought triumph, the reaching of the top of the globe. Reread some of the stories of early exploration and see how the food ration was the leader's problem. As the crew grew hungry, there was always danger of mutiny. Columbus' men could count the food supply stored in the hold of their vessels and reckon it in terms of days. When only enough food was left to take them safely back home, they were ready to turn around. It took all his authority and faith in the unknown land toward which they were sailing to keep the vessels headed westward. He counted on a fresh food supply for the daily ration on the homeward voyage; his men could see nothing but the diminishing pile of stores in the hold. We cannot blame them too harshly. We live on the daily ration plan. Our minds and bodies are trained to its habits.

Courtesy of American Museum of Natural History

A SAMPLE MENU FOR A CHILD'S SUPPER

1 cup of cream of tomato soup (200 calories), 2 slices of bread (100 calories), ½ tablespoonful of butter (50 calories), 5 prunes and 4 tablespoonfuls of juice (200 calories), 1 cup of milk (150 calories), and 2 cookies (100 calories). The whole day's food as here pictured gives a total heat value of 2200 calories.

HOW HE HAS GAINED INDEPENDENCE

As he has learned to prepare, store, transport, and preserve food, man has become more independent in the handling of his daily ration. In the temperate zones he has always carried food over from harvest time into the barren winter season and the seedtime before the fruits of the earth were ready for his larder. Even the squirrels store nuts against the time when they cannot gather them. But man has gone farther and farther in the matter of storing and transporting his food. The American achievement of feeding an army three thousand miles and more from its base of supplies was the greatest food triumph the world has yet seen. The Germans could not believe that this would be achieved. Since the days of Napoleon's pronouncement that "an army travels on its stomach," and back of that in the times of Caesar and the Gallic wars, the limit of an army's reach had been its food supplies. To them it was tied as if by a tether. American energy and determination combined with accurate knowledge of food values, the kind of knowledge that you have been getting in the last few pages, to accomplish this feat. The American soldier, though taken completely off the land and sent three thousand miles from home across an ocean fraught with dangers from enemy attack, was the best-fed soldier in the world. His ration weighed four pounds and a half to Peary's two pounds and a quarter. It does not look wonderfully attractive or appetizing, but it kept the soldiers sufficiently well-nourished to carry on their necessary activities. One and a quarter pounds of fresh beef, one and an eighth pounds of flour, one and a quarter pounds of potatoes, beans, prunes, coffee, sugar, milk, vinegar, salt, pepper, lard,

Courtesy of American Museum of Natural History

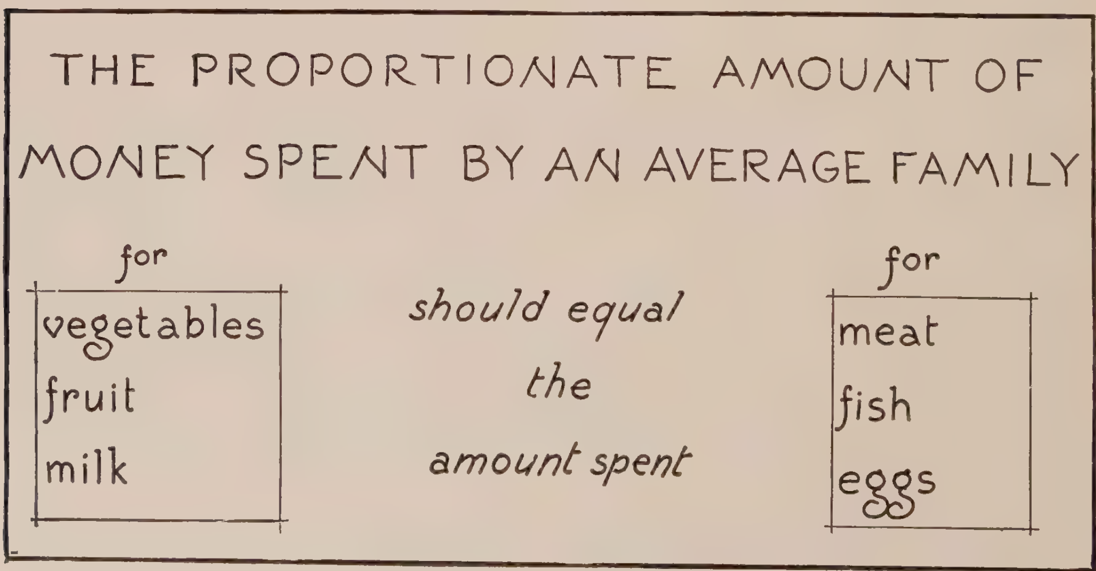
A TYPICAL DAILY FIELD RATION FOR AN AMERICAN SOLDIER

Bread, potatoes, beans, bacon, coffee, sugar, salt, pepper, butter, lard, milk, vinegar, fruit preserve or fresh fruit.

butter, syrup, and baking powder in small amounts — such made up the list of the garrison ration for the American soldier. Parallel with it in the army requirements were lists of substitutes, giving other meats, fruits, flour products, etc., which could take the places of those specified; but below this amount and this proportion of different kinds of food the ration was not to be allowed to fall.

It was a duty from the military point of view to keep the bodily machines of the soldiers in good fighting trim as well as a humanitarian requirement always to feed adequately the men summoned from the land for any public service.

The need for a daily ration lays out and prescribes much of the daily and weekly routine of a man's life. It holds him to the land; it keeps him at work; it holds him to his family with whom it must be shared. It requires a certain amount of forethought on his part. It bounds and limits a man even while it gives him priceless freedom of movement and activity. There is a balance here which is undoubtedly good for man, else he might become a careless, roving creature. But while it limits him in these ways, it is also the measure of his independence. Granted his daily ration, he can go anywhere and do anything.



Courtesy of American Museum of Natural History, New York

ALIKE IN FUEL VALUE, UNLIKE IN PRICE

A BALANCED DIET

How to apply food knowledge to our daily lives.

WITH food provision a daily necessity, a knowledge of food values to serve as a help in its selection is both practical and rewarding. The family pocketbook is concerned; personal pleasure in eating is involved; and good health waits on a wise choice. A balanced diet is one in which all these factors are taken into account.

An acquaintance with food values makes for economy. Since food is needed for fuel, a goodly supply must be provided. Yet cereals, bread, and potatoes can be used in large proportion to meet this body need, instead of having the more expensive foods turned to this use. A quart of milk has the same fuel value as eight eggs or as nine ounces of round steak; yet how different the prices! War discussion of foods made us familiar with the idea of substitutes.

Our food study makes us see why certain less expensive or more easily obtainable foods can be substituted for the more familiar or usual products without any great loss to the diet. It all depends on what they will furnish for body use. Save for the vitamine involved, a butter substitute will furnish an amount of food value equal to that in a similar quantity of butter. If it will serve as well, why not use it in certain kinds of cooking or in other ways when the difference will not be noted? One who understands the place of sugar in diet will not overcrowd the body with this fuel; nor will meat take so large a place as it does on some tables. Yet the wise provider will be equally careful not to eliminate the necessary life foods which no excess of fuel foods can supplant. Recent health examinations of the children of well-to-do families show that they are as likely as are those from poorer homes to suffer from a lack of proper balance in their diet.

Milk comes out from all tests with the highest standing as an all-round food. Because milk is in liquid form we are apt to think of it as a drink rather than as a food. Milk is a food with more "solids" in it than many foods which would appear to have less liquids. Milk is eighty-seven per cent water, but the other thirteen parts are all precious food ingredients. Compared with other foods, milk has more solids than onions, beets, carrots, squash, turnips, oysters, cabbage, spinach, pumpkin, and many similar vegetable foods. Milk comes nearest of any food to being a complete diet in itself. It has fat in it and a milk sugar; it has two proteins; it has needed mineral elements.

It is easily taken up by the human body; it is easy to cook with; it fits in with the other foods of an average menu and makes up for what they lack. The United States Food Administration is sponsor for the statement that "the greatest factor of safety in human diet is the regular use of milk." Milk is economical, whatever its price, as compared with most other foods. "You can get more for your money in milk," says a well-known food expert, "in actual food value, in energy, in protein, in repairing and building properties, than in any other food in the world." Milk is almost, though not quite, a balanced diet in itself.

Our study has not taken us into a detailed analysis of fuel value of food as measured in calories. The menus for a child's food suggested in the exhibit of the American Museum of Natural History, shown on earlier pages, give an idea how certain familiar foods are measured for fuel. The average requirement for a man or woman in ordinary life runs between twenty-two and twenty-six hundred calories a day. For convenience this is usually reckoned in one hundred calorie portions, that being about an average serving of most foods. For instance, the following are one hundred calorie portions of familiar foods: a corn-meal muffin, two slices of white bread, a cubic inch of butter, a large boiled egg, five-eighths of a cup of milk, a cup of oatmeal (cooked), a large apple, a medium-sized potato. The usual menu of the average family may be counted on to supply a sufficient amount of fuel foods. It is on the line of life foods, of fresh vegetables, of milk, of eggs, and of fruits that care must be exercised, with a constant watchfulness not to exceed the proper ration of sweets or of meat proteins.

Eating would be a dull business if reckoned only in food values. The function of the housekeeper is to make the necessary foods attractive and palatable. Here planning, cooking, and serving take an important place. To have enough of the comparatively flavorless fuel foods, like potatoes, bread, and cereals, and then to add to them enough of the life foods in wise proportions between meats, vegetables, and fruits, with sugar for sweetening and with flavoring put in for good measure, is an art calling for no common skill and attention. Cooking under these circumstances becomes a most interesting as well as an important craft. The successful cook who keeps her family well conditioned and with good appetites deserves all honor.

Even the cook cannot attend fully to the matter of a balanced diet for each member of the family. That belongs to the business of eating, which each person must manage for himself. There appetite and inclination come in; they must be balanced with intelligence and common sense. Animals may have retained a sufficiently unspoiled sense of taste to use it as a safe guide in food selection. With the multiplicity of complicated foods prepared for the eating of civilized man, the sense of taste is only a partial guide. Taste can be trained. It is possible to learn to like new foods and foods which do not at the first moment make a particular appeal. Since our likes and dislikes at the instant of eating have an important bearing on digestion, as we learned in the study of "Our Servant Taste," it is really essential for our continued well-being that we get reasonable enjoyment from what we put into our mouths. A healthy person is blessed with a good appetite. With that as a basis, he can take account of stock in his eating, see what essentials he is in danger of leaving out of his daily ration, and plan his meals accordingly. We all want to keep well. If we know that more vegetables are good for us, we shall be able to take an interest in eating more vegetables. If we feel we are taking an excess of sugar or of meat, we can look about in these food lists and see what would be desirable and pleasant substitutes. The one thing that is sure to make for a safe and well-balanced diet is variety. Nature has made a clever distribution of necessary elements in vegetable and animal products. If we eat a good variety of foods, we get what we need. The proper management of our food business will be along two lines, — to select wisely, and then, besides eating what we like, seeing that we like what we should eat.

A GOVERNMENT WAR POSTER

ON BEING HUMAN

Of the advantages and the possibilities — of man in his conquest of time and space, his control over matter and energy.

IT takes a wise man to appreciate the blessings of his own lot in life. Many a traveler has journeyed far to return to his home with a fresh realization of its advantages and possibilities. We who have followed the trail of life through the plant and animal worlds find ourselves prepared to dwell with renewed appreciation on those things which God has given us richly to enjoy. Even against the vivid and varied background of plant life and animal life, the advantages of being born into the human family stand out more clearly and sharply than they ever did before. The inheritance of mankind is unique. It is rich in privilege and compelling in opportunity. "The Wonder of Life" is nowhere so plainly visible as in the experiences and possibilities of the life of a man, a woman, a child. Let us take time frankly to congratulate ourselves on the joys and advantages of "being human."

MAN AS "TIME-BINDING"

A Polish thinker, Korzybski, has given us this new and suggestive phrase for a chief distinction between man and all other living things. Man, he says, is "time-binding." We closed our chapters on "The Machinery of Our Bodies" when the story of speech led us to a consideration of word memories, and from memory led us into the realm of mind. Here machinery became the servant of something which was beyond itself. All this phase of man's life, as distinctive from that of plants and animals, Korzybski characterizes as "time-binding." Plants are "chemistry-binding." "They are a class of life which appropriates one kind of energy, converts it into another kind and stores it up; in that sense they are a kind of storage battery for the solar system." Animals move. "They have a remarkable

freedom and power which the plants do not possess — the freedom and faculty to move about in space." They are therefore characterized as "the space-binding class of life." Man, like the animals, is space-binding; "but, over and above that, human beings possess a most remarkable capacity which is entirely peculiar to them." This capacity he defines thus: "I mean the capacity to summarize, digest and appropriate the labors and experiences of the past; I mean the capacity to use the fruits of past labors and experiences as intellectual or spiritual capital for developments in the present; I mean the capacity to employ as instruments of increasing power the accumulated achievements of the past generations spent in trial and error, trial and success; I mean the capacity of human beings to conduct their lives in the ever-increasing light of inherited wisdom; I mean the capacity in virtue of which man is at once the heritor of bygone ages and the trustee of posterity. And because humanity is just this magnificent agency by which the past lives in the present and the present for the future, I define humanity, in the universal tongue of mathematics and mechanics, to be the time-binding class of life."* The phrase is picturesque and enlightening. It brings vividly and clearly before our minds one of the chief advantages of being human. Surely enough man does "bind time," and by this capacity he links past, present, and future in a way that contributes untold richness to his life.

AN INCREASING CAPACITY

Let us think out for ourselves how "time-binding" has become increasingly a determining factor in the history of mankind. Speech, which is a universal characteristic of human beings, provides for communication of one with another. Along with speech runs the power to remember. Not only the past of the life of a single individual but the past of a group or tribe or nation can be handed down from generation to generation. This is a distinct "binding of time." Time enters in as an element, almost a dimension of life. Many of man's most epoch-making inventions have been in this line. With the invention of writing, a great step forward was taken. The records of the past depended no longer on the presence or absence of certain individuals. By means of a permanent record the past became in a new sense the possession of the present. "The minds of all ages," says Ellsworth Huntington, "become available to the mind of to-day." Printing, which made the written word available by providing practically unlimited duplicate copies of any important work, made the possibilities of this method of uniting past and present universal. Parallel with writing came the graphic arts,—drawing, painting, sculpture, and, in our own day, photography. Our children and our children's children will have another link with the past. Through phonograph records which are being taken to-day, they should be able to hear the voices of men and women who will, in their time, have been long gone from the earth.

TIME AS A DIMENSION

It gives us a new and vivid sense of differences long noted in the physical and mental world to think along these lines — of plants with their power of growth as "one-dimensional" (even as in the literal phraseology of our geometries a line is said to have one dimension, a plane or surface to have two dimensions, a cube or block, three); of animals, with their capacity to grow and to be active in space as, in a figurative sense, "two-dimensional"; and of "humans, with their capacity to grow, to be active in space and to be active in time" as "three-dimensional." The man who suggests these phrases is the first to say that such illustrations "must not be taken too literally; they are like figures of speech — helpful if understood — harmful if not understood." To us who have been at pains to follow out the characteristics of each great group of living figures, they will be helpful if they put into pictures, which we can hold in our minds, some of these distinctions. They cannot be pushed too far. Plants and animals are "time-binding" in certain limited senses, as they grow within time limits and maintain a continuity of existence by passing on their life to the next generation. Animals go beyond plants in some sort of

* From "Manhood of Humanity," by Alfred Korzybski.

memory records which influence their lives. All three classes of life are "chemistry-binding" in the sense of transforming one kind of energy into another, and plants, as we have seen, overcome the difficulties of being rooted in a single spot by many ingenious methods. But surely man alone lives consciously in time. He alone guides his life by calendars, projects himself into the past by means of history and into the future by means of prophecy and invention, seeing all the while himself as a comparatively unimportant unit in a succession of hundreds upon hundreds of generations of mankind.

Here we are bidden to think of time as, in a figurative sense, a new dimension, because man can be "active in time." Einstein elucidates astronomical and other mysteries by treating time as, literally, a fourth dimension which must be reckoned with in mathematical calculations. If time is so important a measuring rod in our earthly human life, we turn with a reverent wonder to the thought of God, with whom time and eternity are one, and a thousand years are as a day and a day as a thousand years. It may be that as we are translated from this earthly life into a higher life, we shall be graduated from this time dimension, which has served us so well, into a larger freedom. However that may be, while we live in time let us make the most of that precious period of time which is allotted to us.

> "Forenoon, and afternoon, and night; — Forenoon,
> And afternoon, and night; Forenoon, and, — what?
> The empty song repeats itself. No more?
> Yea, that is life; make this forenoon sublime,
> This afternoon a psalm, this night a prayer,
> And time is conquered, and thy crown is won."
>
> EDWARD ROWLAND SILL

MAN AND SPACE

There are three ways in which man has conquered space, two of which he shares in some measure with the lower creation, while in the third he stands alone. The first is in regard to actual physical freedom of movement. We have discussed this frequently in the consideration of plants as staying still and animals as moving. Dr. Troward puts into a brief paragraph the idea of how man's gain in intelligence is matched by a gain in control of his movements. He is discussing what it is to be alive, to be living. "There is, of course, one sense," he says, "in which the quality of livingness does not admit of degrees; but there is another sense in which it is entirely a question of degree. We have no doubt as to the livingness of a plant, but we realize that it is something very different from the livingness of an animal. Again, what average boy would not prefer a fox terrier to a goldfish for a pet? Or, again, why is it that the boy himself is an advance upon the dog? The plant, the fish, the dog, and the boy are all equally alive; but there is a difference in the quality of their livingness about which no one can have any doubt, and no one would hesitate to say that this difference is in the degree of intelligence. It is the possession of greater intelligence that places the animal higher in the scale of being than the plant, the man higher than the animal, the intellectual man higher than the savage. The increased intelligence calls into activity modes of motion of a higher order corresponding to itself. The higher the intelligence, the more completely the mode of motion is under its control." This gives the other side of Bergson's thought. Bergson says that the use of movement makes for intelligence; Troward says that with the higher intelligence comes movement which is freer and more under conscious control.

Man has conquered space in the sense that he can go where he pleases the wide world over. He can construct boats and wagons and automobiles and trains which will take him where he will. He has even made flying machines which enable him to conquer in a measure space in its third dimension. Parallel with man's freedom of movement, which has enabled him to encircle the globe, is his ability to live anywhere and eat almost anything. This comes, as we have seen, from his physical powers, from the adaptability of his bodily machine. He can live in the arctic regions; he can be comfortable in the tropics. Moreover, he can change from one to the other without serious inconvenience. Physically he is wonderfully adaptable. His one limitation is the need of food. What he cannot find in any region he can, however, transport. Within the limits of our own planet man has in his exploration and colonization gone far in the conquest of space. If

we spoke of the first means of conquering space, by actual freedom of movement, as purely physical, we might consider this conquest of the earth as geographical.

The third means of conquering space is mental and spiritual, though supplemented by physical agencies. Man can think space which he cannot enclose within the boundaries of his own physical reach or traverse on his own two feet. He can conceive a universe in which he himself is only a small figure. Having done this, he can make instruments which will so extend his physical powers that he does literally conquer space in what he sees. He can by the telescope bring distant worlds within his range of vision. He can go beyond that and take actual measurements of distances so great that the mind staggers before them. (Consider the distances conceived in the imaginary journey through space as pictorially presented in Volume I at page 14.) A recent astronomical study discusses nebulæ which are hundreds of billions of billions of *yards* away, and records differences in distance as if the measurements were comparatively exact.

The lay reader looks upon such scientific investigations as almost superhuman. The scientist who has made them considers them but a step on the path to the greater knowledge of the future. He turns from them to write a paragraph like this, taken from the pages of a scientific journal. "Our Apple" is the title for the article, which opens thus: "What do we know about the planet we live upon? We have determined its shape; we have measured its size; we have estimated its weight; we have climbed its mountain peaks and delved into its ocean depths; we have winged our way up into the envelope of the atmosphere and soared far above the clouds, but there are lofty heights that have not yet been scaled, profound depths that have not been sounded, and vast areas that have not yet felt the tread of human feet. . . . In some respects we know more about the sun than we do about our own planet. We have actually discovered elements on the sun before they were found on the earth. At best our knowledge of the earth is not even skin deep. The skin of an apple measures in the neighborhood of a hundredth of an inch in thickness. The apple — a large one — is, say, four inches in diameter. Enlarge it to the diameter of the earth and the skin will measure about twenty miles in thickness. What do we know about the skin of our apple?" Such it is to be human and to be a scientist. "A man's reach should exceed his grasp, or what's a heaven for?" The scientist begins to make his heaven on earth by reaching out into the boundless realms of knowledge.

MAN'S CONTROL OF MATTER

When we come to the control which man exercises over matter, we are on ground familiar to every one. Here each person can multiply illustrations indefinitely. With his delicate, capable hands as instruments man has fashioned tools and machines by means of which he works wonders with matter. By the use of fire he exercises a unique control over matter, taking a part with Nature itself in transformations by chemical and other means. By his mental grasp of the principles of mechanics and of the laws of the physical world he has harnessed the elements to do his bidding. By the telephone and by wireless apparatus he has taken within the last few years a long step forward in a new conquest of space. Through the agency of the microscope he is discovering "worlds within worlds" which when explored can be made to minister anew to his comfort and convenience.

MAN'S CONTROL OF ENERGY

This is the newest field in which man is adventuring. Of sun energy as caught in plants man has made the same physical use that animals of lowest orders have done, as described in "The Cycle of Life." By the use of fire he has turned this energy to his own purposes, especially by the unearthing of the sun energy of forgotten ages in the stores of coal buried in the earth. In a few instances, as in sun motors or power plants run by the tides of the sea, he has tapped in another way these sources of energy. Now in this twentieth century he catches a glimpse of the wonderful possibilities of atomic energy as briefly set forth in earlier chapters. To the possibilities of future employment of this energy scientists put no limit.

MAN'S PARTNERSHIP WITH NATURE

When man works with Nature he is dealing with life. He is in a partnership in which the great life forces are utilized. Here he has accomplished some of his most wonderful results. With the ordinary coöperation of man with Nature we are familiar. The farmer and the gardener practice it daily. By their increased knowledge of life processes and of chemical reactions they are becoming able to practice an intensive cultivation of the soil which works well in the present and promises wonders for the future when the food supply of the world shall need further replenishing. Luther Burbank and others working in his field have carried the partnership still further until they almost take the part of Nature itself. Having carefully studied the laws of life in certain plants, Mr. Burbank so mates and combines them as to produce new plants which will propagate themselves independently from generation to generation. He takes a thorny cactus that grows in regions where nothing else will grow but is of no service to mankind, and transforms it, in ten years of patient labor, into a spineless cactus with an edible fruit. Whole regions of arid land may in a later day be transformed into possible abiding places for men and animals by such magic manipulation of plants as he practices. In such work man is guiding the life forces which are at work in every age to make the earth bring forth fruit in its season.

Men of the medical profession are dealing constantly with life. Grown weary of simply patching up human beings after they have become disabled, they are educating the world to a prevention of disease which holds high promise for the future. The laws of life as they should be kept by every human being were never so well understood as they are to-day.

Man was given dominion over the earth, and he takes it. Plants and animals contribute to his comfort and serve his convenience. In every department of life the control which he is exercising is becoming more complete. More and more he is becoming in his own right and independently a worker of wonders. Such it is to be of the human family as it relates itself to the physical world.

WHAT OF THE INDIVIDUAL?

All honor to mankind for its accomplishments, we may say, — but what of ourselves? what of the individual? What to each one of us are the personal advantages of being human? We have this different sense of time from any possessed by animals; we have the wider use of and idea of space; we have more control over matter and energy, and therefore more powers of action, more comforts, a more elaborate civilization; we can work as partners with life in the plant and animal worlds. So far the question has been answered, but such general statements, while convincing, leave us cold. The real difference goes deeper. The endowment of life as it comes to every human being carries with it the gift of mind and spirit, of individuality and of personality. Only the scientist talks of men in general; the rest of us are concerned with men and women as individuals, as interesting and separate personalities. Therein lies one of the fascinations of being human. We are more than members of a huge group. We are ourselves, each one of us with an interesting personal past history and inheritance, each one of us with a future of unlimited possibility before us.

Individuality comes with the higher mental and spiritual powers which we all possess as members of the great human family. With it go elements of choice which further mark our separation from the life of the lower creation. The instincts which were there followed blindly are with us followed consciously and with intent. An animal must preserve himself, must look after his family, must acquire food for their common needs. In the higher animals the sense of family may be extended to the herd instinct. The individual may even sacrifice some of his separateness for group life. But how different is all this from the social life which we as individuals carry on with each other! How much more rich the human intercourse of the family, of the circle of friends and neighbors, of the community, of the nation, and of the world! An animal must be concerned about his own petty affairs; they absorb all his time and energy. We can carry on our life business and still have a great surplus of energy and interest free for a larger life.

OF LIFE IN A MAN

Man is so richly endowed with life that his possibilities are practically unlimited. He alone worships his Maker and shares in some small measure in the creative spirit which makes and remakes the world. He alone seeks fellowship with the Divine and aspires to a spiritual communion with his God. He learns to sink his own interests for the good of the whole and finds his highest happiness in so doing. In the midst of the World War the American people were willing to put themselves voluntarily on rations and to send part of their own food supply to feed hungering peoples across the seas. Each individual might have been ready to feed a starving neighbor at his door. The marvel was that individuals merged in a great nation were almost equally ready to perform this service for other nations. In such an act humanity as a whole takes a step forward.

Human beings as they are at present on the earth are the supreme product of life. They stand so far beyond all the other orders of creation as wholly to outdistance them. Life fulfills itself best in human beings, and will so continue to fulfill itself. On earth, as John Fiske has said, there will probably never be a higher being than man, never a higher life than manhood life. But there are possibilities in human life which are yet to be reached. The world of each of the lower creatures was measured by his powers; it was bounded by what he could "sense." To each one of us comes the challenge as to how limited is our own world. With our human powers, physical, mental, and spiritual, as we may develop them, the bounds of our world may touch the infinite.

Into the higher realms of mind and spirit it is not the province of this volume to go. The book will have served its purpose if it has helped to push back the horizon lines a little farther and made the world for each one of us a bigger and a better and a richer place in which to dwell. "The Wonder of Life" runs through the whole creation, but only in the upward, onward reach of each separate human being and of humanity as a whole can it reach its highest fulfillment.

Photo by Wm. L. Finley and H. T. Bohlman

ANIMAL SECTION OF "A NINE-MILE COLUMN OF LIFE" (PAGE 7) ENLARGED

NOTES

A detailed bibliography for this volume would list a large number of sources from which single facts have been taken or by which they have been checked. Such a list would be of little interest to the general reader, except to testify to the carefulness with which each field has been covered. The reader will be willing to take that for granted without the detailed enumeration. In our presentation of facts we have kept in mind the humorous advice of Josh Billings that "it is better not to know so much than to know so many things that aren't so."

Each separate field of knowledge has its special modern books. No single volume covers, so far as we know, so wide a field as this. We have endeavored by frequent quotations to bring our readers into touch with the best modern authorities. There are certain books along parallel lines to which we wish to call the attention of the reader who desires to pursue any subjects further.

Part One. "The Wonder of Life." After the book was planned and more than half written, with its title selected and the main idea adopted of tracing "The Wonder of Life" through the plant and animal worlds, including the final study of the human being, the author was fortunate in coming upon the books of one of the leading British authorities in this field, Dr. J. Arthur Thomson, Regius Professor of Natural History in the University of Aberdeen. Any interested reader is recommended to one or more of his books, published in England and handled in this country by Henry Holt and Company, of New York. One bears the title of this volume, treating the subject of life from the vitalistic standpoint and tracing it in scholarly fashion through evolutionary processes. Other popular books are "The Biology of the Seasons" and "Secrets of Animal Life." The author has been glad to make frequent quotations showing how our conception of life is reënforced by so leading an exponent of vitalist in contrast to mechanist theories as this learned British scholar.

The plate facing this page is an enlargement of the animal section of "A Nine-Mile Column of Life" on page 7. Our artist had taken such pains in the drawing of each separate creature that it seemed our readers should be able to study out the individual animals as well as to get the total effect. Familiar animals will help in the locating of those less familiar in the following list.

At the top, the condor, the eagle, and the yak, with the vulture (on a rocky crag), the llama, and the vicuna, with the spectacled bear between them directly below. The African elephant, the tiger, and the musk ox hold the next level. The Rocky Mountain goat, the gelada, the armadillo, the warthog, and the bighorn, or Rocky Mountain sheep, occupy the next row. The grizzly bear, the black bear, the puma, the elk, the pronghorn, with the Cape buffalo just below, make a more familiar row. From this range to sea level the animals are far more numerous. Following from left to right the reader will locate in the next group the leopard, the black wolf (the lion, below), the horse, the coyote, the zebra, the burro, the porcupine (the peacock and the cow, below), the moose (the mink, the fox, the squirrel, and the skunk, below), the giraffe, the gnu, and the pig. Then come the kangaroo, the deer, the dog, the sheep, the lynx, the raccoon, the squirrel, the sable, with below them the camel, the goat, the snake, the turkey, the rabbit, hares, and birds. At sea level are the hippopotamus, the crane, the rhinoceros, the alligator, the swan, the penguin, the elephant seal, the sea otter, the Pacific walrus, sea lions, and the polar bear. The sea cow, the whale, and many fishes are shown in the water.

It is a pleasure to pay tribute to the skill of our leading Nature artist, Mr. L. J. Bridgman, who has contributed many of the finest drawings and color sketches for this volume, among them the "Noah's Ark" of animals here enumerated.

The clear distinctions drawn in chapters of Part One between plants and animals in their relation to movement, with the consequent effects, are based on the philosophy of Henri Bergson, especially as presented in his epoch-making book, "Creative Evolution," published by Henry Holt and Company, to which the thoughtful student is directed.

Part Two. "The Cycle of Life." A leading book in this field is "The Living Plant," by William F. Ganong, published by Henry Holt and Company. The concept of life as related to energy comes from "The Origin and Evolution of Life," by Henry Fairfield Osborn, published by Charles Scribner's Sons.

Part Three. "Life in Three Zones." This field is covered very fully in Dr. Thomson's books, above cited, as well as in stories of each animal. Studies of flight are found in recent scientific journals; a historical background is also found in Dr. Osborn's book, above cited.

On pages 83 and 84 the word "animals" is used in its popular sense of "quadrupeds" or "beasts," as distinguished from birds and fishes, not in its technical sense of "animal" as distinguished from "plant" life.

Part Four. "Life the Master Builder." Two books which every reader of this section would enjoy are "The Bird: Its form and Function," by Dr. William Beebe, published by Henry Holt and Company, and "The Childhood of Animals," by P. Chalmers Mitchell, published by Frederick A. Stokes Company.

On page 115, in a mention of the pigeon guillemot, reference is made to the picture of Professor Sharp with a murre in Volume III. The murre is a guillemot.

Part Five. "The Business of Living." Vernon Kellogg's "American Insects," published by Henry Holt and Company, is a reference volume for one interested in these lines.

Part Six. "The Five Senses -- and Others." The author is glad to acknowledge indebtedness to "Animal Secrets Told," by Harry C. Brearley, published by Frederick A. Stokes Company, a suggestive popular book, as well as to Dr. Gregory's studies of the development of faces in *The American Museum Journal.*

On page 151, in the contrast with man, the spider is referred to as "he," though it is more often the female whose industry would be sufficient for such a task.

Part Seven. "In Life's Workshops." The book referred to in the last chapter is "The Fitness of the Environment," by Lawrence J. Henderson, published by The Macmillan Company.

On page 251 Mr. Seton's figures for speed are given. The 1921 records for a race horse range from 38 miles an hour for the mile to nearly 42 miles for the quarter mile, while a greyhound made the quarter mile at a rate of 33 miles an hour.

Part Eight. "Each After Its Kind." "Instincts of the Herd in Peace and War," by W. Trotter, is an English book published by T. Fisher Unwin. "The Animal Mind," by Margaret F. Washburn (second edition), published by The Macmillan Company gives a detailed discussion of experimental evidence on these lines.

Part Nine. "Worlds Within Worlds." "The Electron," by Robert A. Millikan, is published by the University of Chicago Press. Readers are referred to current scientific periodicals for new articles on these lines.

Parts Ten and Eleven. "The Machinery of Our Bodies" and "Food and Life." Parents and teachers interested in the new programs for community health should write to "The Child Health Organization," 156 Fifth Avenue, New York City, which has fascinating booklets and charts at almost cost prices. Any child would enjoy the "Child Health Alphabet" which can be obtained there.

Part Twelve. "On Being Human." "Manhood of Humanity," by Alfred Korzybski, is published by E. P. Dutton and Company.

"To see a world in a grain of sand,
And a heaven in a flower,
To grasp infinity in the palm of the hand,
And eternity in an hour."

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